This report presents a proposal for a standardised method for creep tests and the necessary theoretical and empirical framework that can be used to describe creep of a granulated loose-fill material exposed to climate. Furthermore results from a round-robin test are shown. The round-robin test was carried out in collaboration with Norwegian Building Research Institute department of Materials and Structures in Trondheim, SP-Swedish National Testing and Research Institute department of Energy Technology, Building Physics, Ete in Borås, VTT-Technical Research Centre of Finland department of Building and Transport in Espoo and the Danish Building Research Institute department of Building Design and Technology. For the round-robin test a cellulosic fibre insulation material was used. The proposed standardised method for creep tests and theoretical and empirical framework are limited to cases when the granulated loose-fill material is exposed to a climate that is characterised as cyclic humidity conditions (a constant temperature and a relative humidity alternating between two predetermined constant relative humidity levels). A better understanding of the behaviour of granulated loose-fill material is provided and a standardised method is proposed. This enables control of the settling and prediction of densities necessary to prevent settling. The Nordtest, Organisation for Testing in Scandinavia funded the Nordtest Project 1623-03.

1st edition, 2005
ISBN 87-563-1222-9

The project was funded by Nordic Innovation Centre.
Density of loose-fill insulation material exposed to cyclic humidity conditions

Test method and round-robin test

Nordtest project 1623-03

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Title: Density of loose-fill insulation material exposed to cyclic humidity conditions
Subtitle: Test method and round-robin test, Nordtest project 1623-03
Serial title: SBI 2005:02
Edition: 1st edition
Year: 2005
Author: Torben Valdbjørn Rasmussen
Language: English
Pages: 38
References: Page 20-21
Danish Summary: Page 22
Key words: Loose-fill material, insulation, creep, alternating moisture conditions, empirical model, test method, round-robin test
Price: DKK 85.00 incl. 25 per cent VAT
Word processing: Torben Valdbjørn Rasmussen
Publisher: Statens Byggeforskningsinstitut
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Foreword

This report presents a proposal for a standardised method for creep tests and the necessary empirical framework that can be used to determine the density for the volume-stable state of a granulated loose-fill material as a function of the applied stress when exposed to a climate that is characterised as cyclic humidity conditions. Furthermore results from a round-robin test are presented.

The project was initiated, because granulated insulation materials that are loose-filled into walls have been found to settle after installation. Loose-fill insulation in walls in a test house was observed to exhibit progressive settling between 0.07 and 0.38 m.

A better understanding of the behaviour of granulated loose-fill material is provided and a standardised method for measurement of creep of loose-fill material exposed to a specified climate is proposed. This method enables control of the settling and prediction of densities necessary to prevent settling.

Nordtest has supported the project (Nordtest project 1623-03).

Danish Building Research Institute
Department of Building Design and Technology
January 2005

Jørgen Munch-Andersen
Acting Head of Department
Introduction

Background

It is well known that granulated insulation materials that are loose-filled into walls may settle after installation. From practice and experimental observations it is well known that if the density of an insulation material loose-filled into walls is too low, it may settle after installation. For example, a sample of cellulose fibre loose-fill insulation at a low density in a 2.4 m high cavity was observed to exhibit progressive settling, which was 0.07 and 0.38 m before and after removal of the exterior gypsum board sheathing (Andersen et al. 2002).

Today, when loose-fill insulation is used as horizontal insulation in attics, an extra amount is added over and above the level required for insulation in order to solve the settling problem. When used in walls, settling is reduced by adding an extra amount of the loose-fill material in the wall to prestress the loose-fill to compensate for any shrinkage and creep. Mainly the increased density has been added based on experience.

In order to control the settling, or to be able to predict densities necessary to prevent settling of a granulated loose-fill insulation material in walls, a better understanding of the material behaviour must be provided.

Creep is shown to lead to an understanding of the material behaviour that allows for a quantitative approach to the problem of how to achieve non-settling of a granulated loose-fill insulation material in walls. creep of a granulated loose-fill insulation material exposed to a constant climate is described in (Rasmussen, 2001a, 2001b, 2002a, 2002b) and, exposed to one type of cyclic humidity conditions, in (Rasmussen, 2002c, 2003, 2005).

Aim

The aim of this project was to complete and test a proposal for a standardised method for testing creep of granulated loose-fill insulation exposed to a climate that is characterised as cyclic humidity conditions. In addition a round-robin test of the proposed experimental techniques and the use of empirically derived equations to predict creep, and hence to predict the density of a loose-fill insulation material for which the creep of the mass has asymptotically approached equilibrium, were described. The granulated loose-fill material was exposed to a climate characterised by cyclic humidity conditions.

Test Material

The tested loose-fill material was a granulated loose-fill cellulose-based material made from recycled paper and used for thermal insulation. The test material was Ekofiber Vägg from the Swedish manufacturer Nordiska Ekofiber NEF AB, Kallinge o Pilgrimstad, Sweden. In the following it is referred to as cellulose fibre insulation (CFI). CFI is made from recycled paper torn to a maximum size of 2 mm by 3 mm. In total, 5 % by weight of borax and boric acid is added to the CFI to ensure that the cellulose is fire-resistant and resistant to mould growth. The loose-fill material was characterised by being a mass of material consisting of many small separate parts. These small parti-
cles were not bound together in a defined structure. With relatively little ef-
fort, the loose-fill material could be distributed homogeneously over a prede-
 fined area, which was large compared with the size of a single particle.
Summary

This report presents a proposal for a standardised method for creep tests and the empirical framework necessary for determining the density for volume-stable state of a granulated loose-fill material as a function of the applied stress when exposed to a climate characterised as cyclic humidity conditions. The behaviour of a volume of granulated loose-fill material exposed to external load and the specified climate is described by creep tests. For the creep to asymptotically approach equilibrium, a quasi volume-stable state of the granulated loose-fill material was achieved. The empirical framework is used to describe the creep behaviour and to determine the density, at the Equilibrium State of creep, of a granulated loose-fill material as a function of the applied stress exposed to a specified climate.

The proposed standardised method for creep tests and the necessary empirical framework shown are used in cases where the granulated loose-fill material is exposed to specific cyclic humidity conditions with a constant temperature.

Tests

The proposed creep test and its related empirical framework were tested in a round-robin test. The round-robin test was carried out in collaboration with the Norwegian Building Research Institute department of Materials and Structures in Trondheim, SP-Swedish National Testing and Research Institute department of Energy Technology, Building Physics, Ete in Borås and the VTT-Technical Research Centre of Finland department of Building and Transport in Espoo with the Danish Building Research Institute department of Building Design and Technology as the project coordinator.

The round-robin test were performed using cylindrical specimens of 70 mm height and 105 mm diameter as described in (Rasmussen, 2001a, 2002b, 2002c, 2003, 2005). The specimens were placed in a cylindrical test cell. It is assumed that the height of the sample was small compared with its diameter, and the inner surface of the test cylinder surrounding the test specimen was smooth so that the loss of stress from top to bottom was negligible. The base of the test container was a perforated horizontal plate. A perforated circular piston was placed on the upper surface of the test specimen for loading and yet allowing air to flow through. A steady flow of air was forced through the specimen. The relative humidity of the air was changed with time according to the test requirements detailed below.

The flow of air was forced through the test specimens by means of low pressure applied at the base. In this way the relative humidity around the test set-up was used to change the moisture condition in the specimen.

Tests in the round-robin test were carried out at a constant temperature of 23 °C and a relative humidity (RH) alternating between 50 % and 80 %. The round-robin test programme included one test series, described by its density. The density of the test series was 50 kg/m³. For this density three identical specimens of cellulose fibre insulation were tested by exposure to an external load. External loads of 70, 140 and 290 Pa, respectively, were applied to the upper surface of the specimens. The suction pressure on the lower surface was 10 Pa. One specimen was used for every load level.
Every 2 to 4 days the moisture conditions were changed. Displacements were measured as the average displacement of the piston along the vertical centreline of the specimen.

Performance of the individual laboratories is detailed in Results.

Conclusion

It was found to be possible to measure creep and to describe creep by expressing strain as a linear function of logarithm of time at each load level. The constants in the linear function were found using the least squares method. By further empirical framework it was found possible to determine the density of a granulated loose-fill material, CFI material, for which the creep had asymptotically approached equilibrium, as a function of the applied stress for the exposed climate. Equations describing creep were found to be in good agreement with test results. Test results were produced at the Norwegian Building Research Institute, SP-Swedish National Testing and Research Institute, VTT-Technical Research Centre of Finland and the Danish Building Research Institute.

Creep of CFI exposed to a specified climate can be measured and described by expressing strain as a linear function of logarithm of time at each load level. The constants in the linear function were found using the least squares method. It was demonstrated that for many repeated cyclic humidity conditions, creep of CFI asymptotically approached equilibrium. The density of the mass of CFI, at the Equilibrium State of creep at each load, can be determined. The density at this state will be denoted the density for the volume-stable state. With a minimum of one test series, including three specimens of CFI exposed to an individual external load, the density for the volume-stable state as a function of stress exposed to the specified climate can be determined. Results from the round-robin test are summarised in Table 1 below.

Table 1. Summarised results determining the density for volume-stable state of CFI at different laboratories.

<table>
<thead>
<tr>
<th>Density for volume-stable state [kg/m³]</th>
<th>Laboratory A</th>
<th>Laboratory B</th>
<th>Laboratory C</th>
<th>Laboratory D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determined at 80 Pa</td>
<td>54.0</td>
<td>55.1</td>
<td>52.2</td>
<td>50.5</td>
</tr>
<tr>
<td>Determined at 150 Pa</td>
<td>58.8</td>
<td>59.3</td>
<td>56.5</td>
<td>56.4</td>
</tr>
<tr>
<td>Determined at 300 Pa</td>
<td>69.2</td>
<td>68.3</td>
<td>65.8</td>
<td>69.0</td>
</tr>
</tbody>
</table>

Future Recommendations

Normally, CFI is used as an insulation material and will therefore usually be exposed to changing relative humidity. In this report results from CFI exposed to specific cyclic humidity conditions are presented. To be able to evaluate the influence on the results from exposure to other cyclic humidity conditions, tests must be carried out under a number of these cyclic humidity conditions.
A material under instantaneous load will be subject to instantaneous strain, and under continuous load most materials will be subjected to additional strain (Nielsen, 1972). This time-dependent strain is called creep.

Figure 1 shows a typical example of creep as a function of time for a material subjected to a constant load that is subsequently removed. Deformation that occurs during loading is called instantaneous strain. Deformation that develops with time is called time-dependent strain. A deformation that will recover when the load is removed is called reversible. The instantaneous elastic deformation and the time-dependent delayed elastic deformation are reversible. Deformations that remain after a load has been removed are called irreversible. The instantaneous plastic deformation, also called the consolidation, and the time-dependent viscous deformation are irreversible, see (Hagemann, 1989).

\[
\varepsilon(t) = \begin{cases} 
\varepsilon_0 + \sigma_1 c(t), & 0 \leq t < t_1 \\
\varepsilon_0 + \sigma_1 c(t) - (\sigma_1 - \sigma_2) c(t - t_1), & t \geq t_1
\end{cases}
\]

where \( c(t) \) is the creep function that describes the strain that occurs when the material is subjected to a constant stress equal to 1.0, \( (\sigma = 1) \) at the time \( t = 0 \). At the time \( t_1 \), removal of the stress takes place. The constant stress changes from \( \sigma_1 \) to \( \sigma_2 \) at the time \( t = t_1 \). \( \varepsilon_0 \) is the constant instantaneous plastic strain, also called the consolidation. For hygroscopic materials this description is shown to be useful only when exposed to constant environmental conditions. Hygroscopic materials subjected to a constant stress will, when exposed to alternating relative humidity conditions, exhibit additional
strain. Under these circumstances strain can be described by expressing strain as a linear function of logarithm of time at each load level adjusted by the least squares method, given by

$$\varepsilon(t) = p \ln(t/1 \text{ day}) + \varepsilon_1$$

(2)

where, $p$ and $\varepsilon_1$ are regression constants and $t$ is time (days). (Rasmussen, 2002c, 2003, 2005), introduces a purely empirical model describing the relation between the density of the loose-fill material and the applied stress for which the volume of the loose-fill material has become stable in time. A volume is defined as stable in time when creep has reached equilibrium, and additional creep can be ignored. The density for which a volume of the loose-fill material has become stable in time, referred to as density for volume-stable state, denoted $\rho_{v-s}^{\text{RH}_{1-},n}$ ($\text{kg/m}^3$) as a function of the stress, denoted $\sigma_{v-s}$ (Pa) is given by (Rasmussen, 2002c, 2003, 2005)

$$\rho_{v-s}^{\text{RH}_{1-},n} = k^{\text{RH}_{1-},n}\sigma_{v-s} + \rho_{v-s,0}^{\text{RH}_{1-},n}$$

(3)

where, $k^{\text{RH}_{1-},n}$ (kg/Nm) is a constant and $\rho_{v-s,0}^{\text{RH}_{1-},n}$ (kg/m$^3$) is also a constant. $\text{RH}_{1-}$ and $n$ refers to the test history characterised by the minimum and maximum relative humidity and number of cycles, respectively. The empirical model can also describe the behaviour of non-hygroscopic materials (Rasmussen, 2005).
Tests

Tests were carried out as described in the proposal for the standardised method for testing and modelling of creep, see Appendix A.

The proposed test method defines the test container to contain a sample with a diameter/height ratio of 1.5 at test start. The test container was made of acrylic. The height of the sample was small compared with its diameter and the inner surface of the test equipment encircling the CFI was smooth so that the loss of stress from top to bottom of the CFI material could be ignored. Displacements were measured along the vertical centreline of the CFI material.

All laboratories participating in the round-robin test were asked to carry out the same test series. Tests in the round-robin test were carried out at a constant temperature of 23 °C and exposed to a relative humidity alternating between 50 % and 80 %. The round-robin test programme included one test series, described by its density of CFI of 50 kg/m³. For this density three identical specimens of CFI were tested by exposure to an external load. External loads of 70, 140 and 290 Pa, respectively, were applied to the upper surface of the specimens. The suction pressure on the lower surface was 10 Pa. One specimen was used for every load level. Every 2 to 4 days the moisture conditions were changed, see Appendix A, section 7.4.4.

The round-robin test was carried out in collaboration with the Norwegian Building Research Institute, SP-Swedish National Testing and Research Institute, VTT-Technical Research Centre of Finland and the Danish Building Research Institute. The results presented are not addressed to the laboratory that carried out the tests. The results from the round-robin test are addressed to the laboratory that has carried out the tests as Laboratories A, B, C and D. However, Laboratory D did not carry out the same test series as the other laboratories which is why the results of that laboratory are not fully included in this report.

The performance of the individual laboratories is described in Results. The tests carried out at the Norwegian Building Research Institute, SP-Swedish National Testing and Research Institute and the Danish Building Research Institute were carried out using the same equipment, which was circulated between the laboratories. The equipment was manufactured at the Danish Building Research Institute.
Results

Strain-time diagrams determined for CFI at the individual laboratories are shown in Figures 2 to 4. Strain-time diagrams determined for CFI at Laboratory D are shown in Appendix B, Figure 10. The densities were 49.8, 50.4, 50.6 kg/m³ for Laboratories A, B and C respectively. The exposure periods were 2 to 4 days with relative humidity alternating between 50 % and 80 %. The material was exposed to external loads of approximately 70, 140 and 290 Pa, respectively at the upper surface of the loose-fill and a suction pressure of approximately 10 Pa at the lower surface. Throughout the test period, the temperature was kept constant at 23 °C. However, for tests carried out at Laboratory B the material was exposed to external loads of 80, 150 and 300 Pa, respectively at the upper surface of the loose-fill and a suction pressure of 10 Pa at the lower surface. The initial conditions of the material were 23 °C and 50 % RH. For tests carried out at Laboratory C the material was exposed to external loads of 69.7, 143.2 and 291.0 Pa, respectively at the upper surface of the loose-fill and a suction pressure of 8 Pa at the lower surface. The test cell, ready for test, was stored at test start conditions for approximately 24 hours before continuing the test procedure, although the test specifies one hour. The initial conditions of the material were 23 °C and 50 % RH. Tests were carried out in a climate chamber C-20/350 CTS. For tests carried out at Laboratory D the CFI material was tested at a density of 40 kg/m³ and exposed to total external loads of 102, 204 and 408 Pa, respectively. The initial conditions of the material were 23 °C and 50 % RH. Tests were carried out with relative humidity alternating between 53 % and 83 %. Tests carried out at Laboratory D are shown in Appendix B, Figure 10 and partly used in the evaluation of the round-robin test. The test results from Laboratory D are not fully used to evaluate the test method because the density of CFI in the test series differs considerably.

In Table 2 a description of the test series carried out by the individual laboratories are shown.

Table 2. Detailed description of test series carried out by the individual laboratories.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>70.2</td>
<td>10</td>
<td>80.2</td>
<td>49.8</td>
</tr>
<tr>
<td>150</td>
<td>140.0</td>
<td>10</td>
<td>150.0</td>
<td>49.8</td>
</tr>
<tr>
<td>300</td>
<td>290.5</td>
<td>10</td>
<td>300.5</td>
<td>49.9</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>10</td>
<td>90</td>
<td>50.4</td>
</tr>
<tr>
<td>150</td>
<td>150</td>
<td>10</td>
<td>160</td>
<td>50.4</td>
</tr>
<tr>
<td>300</td>
<td>300</td>
<td>10</td>
<td>310</td>
<td>50.5</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>69.7</td>
<td>8</td>
<td>77.7</td>
<td>51.1</td>
</tr>
<tr>
<td>150</td>
<td>143.2</td>
<td>8</td>
<td>151.2</td>
<td>50.6</td>
</tr>
<tr>
<td>300</td>
<td>291.0</td>
<td>8</td>
<td>299.0</td>
<td>50.1</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>92</td>
<td>10</td>
<td>102</td>
<td>40</td>
</tr>
<tr>
<td>150</td>
<td>194</td>
<td>10</td>
<td>204</td>
<td>40</td>
</tr>
<tr>
<td>300</td>
<td>398</td>
<td>10</td>
<td>408</td>
<td>40</td>
</tr>
</tbody>
</table>
Determination of the constants in the creep equation for data for cyclic humidity conditions

Figure 2 to Figure 4 show the strain-time diagram for CFI exposed to a repeated cyclic relative humidity from the individual laboratories. In addition an equation expressing strain as a linear function of logarithm of time at each load level given by \( \varepsilon(t) = p \ln(t/1 \text{ day}) + \varepsilon_1 \) is shown by a bold line. \( p \) and \( \varepsilon_1 \) are regression constants in the linear function and found using the least squares method. \( t \) is time (days). Test data from the fourth relative humidity cycle were used to find the equations expressing logarithm to time as a function.

\[\varepsilon(t) = 6.31 \ln(t/1 \text{ day}) + 1.62\]
\[\varepsilon(t) = 6.54 \ln(t/1 \text{ day}) - 13.95\]
\[\varepsilon(t) = 4.43 \ln(t/1 \text{ day}) - 10.47\]

Figure 2. Strain-time diagram for CFI exposed to 23 °C and cyclic relative humidity alternating between 50 % and 80 % and exposed to external loads of 80.2, 150.0 and 300.5 Pa, respectively. Equations expressing strain as a linear function of logarithm of time are shown in bold lines. The constants in the linear function were found using the least squares method. The numbers at the top indicate the relative humidity in each time period, 5 for 50 % and 8 for 80 %. Laboratory A.

\[y = 7.32 \ln(x) + 2.88\]
\[y = 6.84 \ln(x) - 5.18\]
\[y = 5.69 \ln(x) - 9.08\]

Figure 3. Strain-time diagram for CFI exposed to 23 °C and cyclic relative humidity alternating between 50 % and 80 % and exposed to external loads of 90, 160 and 310 Pa, respectively. Equations expressing strain as a linear function of logarithm of time are shown in bold lines. The constants in the linear function were found using the least squares method. The numbers at the top indicate the relative humidity in each time period, 5 for 50 % and 8 for 80 %. Laboratory B.
Table 3 shows the calculated regression constants $p$ and $\varepsilon_1$ representing the equation expressing strain as a linear function of logarithm of time for CFI at each load level from the individual laboratories. The constants in the linear function were found using the least squares method. In addition the coefficient of correlation $R^2$ for each case is shown in Table 3.

Table 3. Regression constants $p$ and $\varepsilon_1$ representing the equation expressing strain as a linear function of logarithm of time for CFI at each load level and for each laboratory. The constants in the linear function were found using the least squares method. The coefficient of correlation $R^2$ is shown.

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Load [Pa]</th>
<th>$p$ [%]</th>
<th>$\varepsilon_1$ [%]</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80.2</td>
<td>4.43</td>
<td>-10.47</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>150.0</td>
<td>6.54</td>
<td>-13.95</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>300.5</td>
<td>6.31</td>
<td>1.62</td>
<td>0.98</td>
</tr>
<tr>
<td>B</td>
<td>90</td>
<td>5.69</td>
<td>-9.08</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6.84</td>
<td>-5.18</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>310</td>
<td>7.32</td>
<td>2.88</td>
<td>0.95</td>
</tr>
<tr>
<td>C</td>
<td>77.7</td>
<td>4.24</td>
<td>-15.31</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>151.2</td>
<td>5.21</td>
<td>-10.22</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>299.0</td>
<td>6.10</td>
<td>-0.65</td>
<td>0.97</td>
</tr>
<tr>
<td>D</td>
<td>102</td>
<td>5.61</td>
<td>1.82</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>204</td>
<td>8.25</td>
<td>5.70</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>408</td>
<td>6.73</td>
<td>22.82</td>
<td>0.98</td>
</tr>
</tbody>
</table>

**Determination of volume-stable density as a function of stress**

The volume-stable density has been estimated using two different methods. First, by extrapolating data for strain corresponding to 25 relative humidity cycles. Second, by determining the strain at satisfaction of the end of test criteria. The end of test criteria has been satisfied when the vertical displacement of the piston has reached almost equilibrium exposed to the alternating moisture conditions. The piston has reached almost equilibrium when either; 1) showing a change in the strain state of equilibrium less that 0.8 % within the last 3 changes of the moisture conditions, or 2) showing an increase in the strain state of equilibrium less that 0.6 % within the last 3 changes of the moisture conditions, see Appendix A, section 7.4.4.
Figure 5 shows the density of CFI tested at the individual Laboratories A, B and C, respectively for which the creep has reached equilibrium as a function of the applied stress and cyclic relative humidity at 23 °C. From the equation expressing strain as a linear function of logarithm of time at each load level exposed to cyclic relative humidity, a period corresponding to 25 relative humidity cycles (n = 25) was chosen to represent the strain for which creep has reached equilibrium for these experiments (RHl = 50, RHu = 80). From these assumptions the density for the volume-stable state of CFI as a function of the stress is calculated. By the least squares method $k_{RH_l/RH_u,n}$, $(k^{50/80,25})$ and $\rho_{V-s,0}^{50/80,25}$, $(\rho_{V-s,0}^{50/80,25})$ are found, together with the coefficient of correlation $R^2$, to be:

\[
\begin{align*}
\kappa^{50/80,25} &= 0.0768 \text{ kg/Nm} \\
\rho_{V-s,0}^{50/80,25} &= 49.7 \text{ kg/m}^3
\end{align*}
\]

with

\[R^2 = 0.96.\]

25 relative humidity cycles (n = 25) correspond to a period of 175 days, 43 days, 150 days for Laboratory A, Laboratory B, Laboratory C, respectively.

By the least squares method $k_{RH_l/RH_u,n}$, $(k^{50/80,25})$ and $\rho_{V-s,0}^{50/80,25}$, $(\rho_{V-s,0}^{50/80,25})$ are found and shown in Table 4 for the individual laboratories. In addition the coefficient of correlation $R^2$ is shown in Table 4.

Table 4. Regression constants $k^{50/80,25}$ and $\rho_{V-s,0}^{50/80,25}$ representing the linear function describing the density of CFI as a function of the applied load for which the volume of the loose-fill material has become stable over time. The regression constants are found for tests carried out at the individual laboratories. The linear function is found by the least squares method. The coefficient of correlation $R^2$ is shown.

<table>
<thead>
<tr>
<th>Laboratories</th>
<th>$k^{50/80,25}$ [kg/Nm]</th>
<th>$\rho_{V-s,0}^{50/80,25}$ [kg/m$^3$]</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0867</td>
<td>49.6</td>
<td>0.998</td>
</tr>
<tr>
<td>B</td>
<td>0.0663</td>
<td>51.3</td>
<td>0.993</td>
</tr>
<tr>
<td>C</td>
<td>0.0776</td>
<td>48.4</td>
<td>0.999</td>
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<tr>
<td>D</td>
<td>-</td>
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</tbody>
</table>
Density for volume–stable state at satisfaction of end of test criteria

Figure 6 shows the density of CFI tested at the individual Laboratories A, B, C and D, respectively for which the creep reached equilibrium as a function of the applied stress and cyclic relative humidity at 23 °C. The end of test criteria described in Appendix A, section 7.4.4 was chosen to represent the strain for which creep has reached equilibrium. From these assumptions the density for volume-stable state of CFI as a function of the stress is calculated. By the least squares method $k_{R_1/R_1,v,n}^{50/80,End of test}$ and $\rho_{\nu=50,0}^{50/80,End of test}$ are found, together with the coefficient of correlation $R^2$, to be:

$$k_{50/80,End of test}^{50/80,End of test} = 0.0639 \text{ kg/Nm}$$

$$\rho_{50/80,End of test}^{50/80,End of test} = 48.6 \text{ kg/m}^3$$

with

$$R^2 = 0.95.$$ 

By the least squares method $k_{R_1/R_1,v,n}^{50/80,End of test}$ and $\rho_{\nu=50,0}^{50/80,End of test}$, are found and shown in Table 5 for the individual laboratories. In addition the coefficient of correlation $R^2$ is shown in Table 5.

![Figure 6. Density for volume-stable state as a function of the applied stress is shown for CFI tested at the individual laboratories. Linear function found by the least squares method is shown as a bold line.](image)

### Table 5. Regression constants

<table>
<thead>
<tr>
<th>Laboratories</th>
<th>$k_{R_1/R_1,v,n}^{50/80,End of test}$ [kg/Nm]</th>
<th>$\rho_{\nu=50,0}^{50/80,End of test}$ [kg/m$^3$]</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.069</td>
<td>48.5</td>
<td>0.997</td>
</tr>
<tr>
<td>B</td>
<td>0.060</td>
<td>50.3</td>
<td>0.994</td>
</tr>
<tr>
<td>C</td>
<td>0.062</td>
<td>47.2</td>
<td>0.999</td>
</tr>
<tr>
<td>D</td>
<td>0.084</td>
<td>43.8</td>
<td>0.971</td>
</tr>
</tbody>
</table>
Discussion

The round-robin test started with reading, commenting and clarifying the proposal for the standardised method for testing and describing creep of materials exposed to cyclic humidity conditions. Hereafter the actual test and calculations took place. Laboratories A to D carried out the tests using the proposed method.

The test method has been shown to be a method easy to carry out and to reproduce data from. The test procedure used a strain criterion for the change of relative humidity level and an end of test criteria allowing tests to be carried out over a period of time different from one laboratory to another. However, tests show little influence from the total time used to carry out the tests.

Test results show that creep of CFI material exposed to cyclic humidity conditions can be described by an equation expressing strain as a function of logarithm of time for each load level. It is recognised that the suggested empirical framework describing the creep functions can be used for load levels that do not cause damage to the material. Additional tests have shown that CFI, woodwool, granulated flax and granulated mineral wool can be described by the use of the presented test method, (Rasmussen, 2002c, 2005).

Further it is shown that the strain can be expressed according to the number of relative humidity cycles. Test results from the fourth relative humidity cycle until end of test criteria have been used to predict strain after the 25th relative humidity cycle. Laboratory B continued the tests from the end of test criteria until the 25th relative humidity cycle. Results from Laboratory B show a good correlation between predicted strain and measured strain after 25 relative humidity cycles. The predicted strains are 12.32, 20.55, 30.45 % and measured strains are 11.6, 19.5, 29.3 % at the 25th relative humidity cycle for load levels of 90, 160, 310 Pa, respectively.

Laboratory A is seen to have an error related to strain measurements at the load level 150.02 Pa. It was ensured that the strain measurements for the three last relative humidity cycles were without errors and correct. The equipment used to measure the displacement was changed.

Strain time diagrams from the different laboratories show that for many repeated cyclic humidity conditions creep of CFI has asymptotically approached equilibrium.

The density of CFI for volume-stable state as a function of the stress level has been determined at end of test conditions and after many repeated cyclic humidity conditions, 25 cycles. The volume-stable state has been described by a linear equation found by the least squares method.

CFI is normally used as an insulation material and will therefore usually be exposed to changing relative humidity. Here CFI exposed to a relative humidity alternating between 50 % and 80 % at 23 °C have been investigated and results carried out at four different laboratories are shown. Tests carried out at the different laboratories show the test method to be robust. Carrying out the round-robin test, the laboratories have used both a fixed number of days for every climate and the number of days at every climate necessary to fulfill the strain criteria. Both procedures used for carrying out the tests showed comparable results.

Tests carried out at Laboratory D showed that the density at the end of test criteria described in Appendix A, section 7.4.4 which were chosen to represent the strain for which creep has reached equilibrium, is independent of the density of the specimen at test start. From these assumptions the
density for volume-stable state of CFI as a function of the stress is calculated.

It should be kept in mind that material characteristics for hygroscopic materials are moisture-related. Therefore, it is recognised that for hygroscopic materials the moisture exposure is of great importance for determining the density for which the volume of the loose-fill has become stable when exposed to a specified climate. By lowering the temperature or by lowering the relative humidity amplitude, reduction of the moisture exposure will decrease the density for which the volume of CFI has become stable. The density for which the volume of CFI has become stable for environmental conditions different from those shown must be determined from material characteristics related to the actual climate. The influence from ageing of materials and mechanical vibrations including shock has not been addressed in this test method.
Conclusion

This report presents a proposal for a standardised method for creep tests and the necessary empirical framework that can be used to determine the density for volume-stable state of a granulated loose-fill material as a function of the applied stress exposed to a specified climate characterised as cyclic humidity conditions. Creep tests were carried out in a climate with a cyclic relative humidity alternating between 50 % and 80 % at 23 °C. For the creep to asymptotically approach equilibrium, a volume-stable state of the granulated loose-fill material was achieved and the matching density determined. The empirical framework was used to describe the creep behaviour and to determine the density, at the Equilibrium State of creep, of a granulated loose-fill material as a function of the applied stress exposed to the specified climate.

The proposed creep test and related empirical framework were tested in a round-robin test. The round-robin test was carried out in collaboration with the Norwegian Building Research Institute, SP-Swedish National Testing and Research Institute and the VTT-Technical Research Centre of Finland with the Danish Building Research Institute as the project coordinator. The proposed standardised method for testing and describing of creep was carried out at a constant temperature and an alternating relative humidity.

It was found possible to describe creep by the empirical framework in good agreement with test results. Furthermore strain time diagrams from the individual laboratories show that for many repeated cyclic humidity conditions creep of CFI has asymptotically approached equilibrium.

The density of CFI for volume-stable state as a function of the stress level can be determined and described by a linear equation found by the least squares method. It is recognised that the suggested empirical framework describing the creep functions and the density at the volume-stable state can be used for load levels that do not cause damage to the material.

The test method was shown to be robust.
References


Sammenfatning

SBi 2005:02 Cyklisk fugtpåvirkede løsfyldisoleringsmaterialers densitet

Ringprøvning

I denne rapport præsenteres et forslag til en testmetode og dertil hørende empiriske formler, hvorefter krybningen for et løsfyldsmateriale udsat for fugtvariationer kan bestemmes. Testmetoden og formlerne er vist anvendt i det tilfælde, hvor løsfyldsmaterialet er udsat for et varierende klima karakteriseret ved en konstant temperatur og en relativ luftfugtighed som periodisk varierer mellem to faste værdier.

Det præsenterede forslag, til en testmetode og de dertil hørende formler, er blevet afprøvet ved en samkalibrering foretaget i samarbejde med Norges Byggforskningsinstitutt, SP-Sveriges Provningsanstalt och Forskningsinstitut, VTT Building and Transport i Finland og Statens Byggeforskningsinstitut i Danmark.

Samkalibreringen blev udført under et varierende klima karakteriseret ved en konstant temperatur på 23 °C og en periodisk skiftende relativ luftfugtighed på henholdsvis 50 % og 80 %. Samkalibreringen blev udført med et løsfyldsisoleringsmateriale af cellulose.

Samkalibreringen viste, at det er muligt at beskrive krybning for løsfyldsisoleringsmateriale af cellulose under varierende fugtpåvirkninger. Likeledes er det vist at ved mange gentagte fugtpåvirkninger stabiliseres tøjningen for en konstant last og yderligere krybning kan negligeres. For det stabile tøjningsniveau kan løsfyldsisoleringsmaterialets densitet bestemmes og beskrives ved en ret linie som funktion af lastpåvirkningen.
VOLUMETRIC STABILITY OF LOOSE-FILL INSULATION - UNDER ALTERNATING MOISTURE CONDITIONS
VOLUMETRIC STABILITY OF LOOSE-FILL INSULATION
- UNDER ALTERNATING MOISTURE CONDITIONS

Key words: Loose-fill material, insulation, creep, alternating moisture conditions, empirical model, test method

1 SCOPE
This test method covers a description of creep for loose-fill material exposed to in-time alternating moisture conditions. The method consists of a test method and a technique that can be used to adjust test results to an empirical model. The method seeks to model creep in a loose-fill material influenced by and in equilibrium with a number of stable environments constituting a test history.

2 FIELD OF APPLICATION
The method has been specially designed to describe and model the creep behaviour of loose-fill materials exposed to alternating moisture conditions. Results can be used to predict densities necessary to prevent settling of the loose-fill when placed within cavities.

3 REFERENCES

4 DEFINITIONS
4.1 Loose-fill Material
Loose-fill material is defined as a mass of material consisting of many small separate particles and fibres. These small particles and fibres are not bound together in a fixed predefined form. With relatively little effort, the mass of material can be distributed homogeneously across a predefined area, which is large compared with the size of a single particle or fibre.

4.2 Creep
Creep is defined as the strain that occurs in a material exposed to a constant load as a function of time.

4.3 Volume-stable State
The state of a loose-fill material for which creep has reached equilibrium under the imposed moisture cycles is denoted the volume-stable state. The volume-stable state is determined as a function of the applied stress.

5 ASSUMPTIONS
- The height of the test specimen is kept small so that the loss of stress from the top to the bottom of the mass is negligible compared to the measured displacements.
- Displacements are measured along the vertical centreline of the loose-fill material.
- The mass is distributed homogeneously in the test cell at test start and during testing.
- The total stress put on to the test specimen is the sum of all applied stresses.

6 SAMPLING
- A sample of material weighing at least 10 times the total weight of the test specimens is randomly chosen from the batch under test.
- Test specimens should be randomly chosen from the sample.
- The minimum number of test specimens is 3. The test specimens should be of equal mass.
7 TEST METHOD

7.1 Principle
The compression as a function of time of a loose-fill material exposed to alternating moisture conditions and a constant stress is measured. To determine the density of the loose-fill material in the volume-stable state as a function of the applied stress a minimum of 3 specimens subjected to different stress levels must be tested.

7.2 Apparatus
- **Test cell.** An acrylic cylinder with a vertical centreline is fixed to a horizontal perforated acrylic plate, see Figure 1. The cylinder has an internal diameter of 104.5 mm ± 0.5 mm and is approximately 110 mm in height. The test cell also consists of a piston made as a perforated plane disc of acrylic with a diameter 1.5 - 2 mm less than the internal diameter of the cylinder. The piston is provided with small drilled (not riddled drilled) holes made for grips. The perforated plate is approximately 5.5 mm thick, and the cylinder and the piston are both approximately 3 mm thick. The perforations are 1 - 1.5 mm in diameter and are spaced at 10 mm intervals. The cylinder is marked on the outside at a horizontal plane at 3 angles (120°) at every 10 mm vertically from the bottom plane. The piston is to be fixed in a position where the distance from the bottom to the underside of the piston is 70 mm. This can be done by sticks put through holes drilled in the cylinder.

- **Weights** that should be easy to add to the upperside of the piston, i.e. nuts, see Figure 2. For heavier loads it is recommended to use load discs with load hangers. However, care should be taken not to cover the holes of the piston.

- **Low pressure supply.** A low pressure of approximately 10 Pa is established at the bottom plane at the area encircled by the cylinder of the perforated plate. The low pressure can be established mounting the test cell on top of a box that is connected to a flexible tube mounted a small ventilator, see Figure 1 and Figure 2. The flexible tube is used to prevent transmission of vibration from the ventilator to the test set-up.

- **Stamper.** An approximately 200 mm stick is mounted perpendicular to a disc. The diameter of the disc is 1.5 - 2 mm less than the internal diameter of the cylinder. The disc is perforated. The perforations are 1 - 1.5 mm in diameter and are spaced at 10 mm intervals. The disc is made of acrylic and is approximately 5.5 mm thick.

- A **displacement measuring system** with the capability of measuring at least 12 mm of displacement with an accuracy of ± 0.1 mm. An LVDT displacement transducer mounted on a bridge that can be mounted on top of the cylinder can be used. The position of the displacement transducer should be adjustable.

- A **data logger** with a sampling frequency of 30 sec. and a data-logger control system for example a PC.

- A **balance** capable of weighing up to 0.5 kg with an accuracy of ± 0.0001 kg.

- **Plastic gloves** for example disposable surgeon gloves.

- A **light form of respirator** should be used.

- **Tweezers.**

- **Containers** for handling and storing the material for example 0.5 l disposable tankard.

- **Climate chamber** capable of keeping the relative humidity and temperature constant with an accuracy of ± 3% and ± 2 °C, respectively.

7.3 Preparation Prior to Testing
- Prior to exposure, information about the sample is registered, e.g. manufacturer, identification (name and type), production method, date of manufacture.

- The sample is kept in the conditions specified by the supplier until test preparations are carried out.

- The test cell and the stamper are washed in soap and warm water (approximately 35 °C) and afterwards rinsed with distilled water before being dried lightly with a paper towel and finally air dried.

- Decide on the test conditions given by the two moisture conditions the environment around the test-set-up will be alternating between. The two moisture conditions are characterised by the temperature and the relative humidity.

- The sample of loose-fill is loosened by blowing pressurised air through the mass in a closed box mounted a vent that prevents loss of material before test specimens are taken.

- All test equipment and the loosened sample of loose-fill material are conditioned to test start conditions before testing.
The organisation or the persons that ordered the test specify the density of test specimens. A guideline for a usable combination of density and the applied stress is given in 7.3.1.

7.3.1 Guideline; Determining a usable Combination of Density and Applied Stress for Testing

The guidance is given for a dry loose-fill material with a coefficient of friction at the interface between a smooth acrylic plate and the loose-fill material of approximately 0.3. The suitable combination of density of the test specimen and the applied stress used in the test is determined in the following way: A predetermined density of the loose-fill material, mounted the test cell as described in 7.4.1, is mounted a predetermined stress, as described in 7.4.2. If the measured strain of the loose-fill is determined to be approximately ± 5 % within the first 5 minutes of the test a suitable in-between value for the applied stress is found. Suitable lower and higher values of stress are found to be approximately half the predetermined stress and twice the predetermined stress, respectively. However, applied stresses less than 80 Pa is not recommended.

7.4 Procedure

7.4.1 Preparation of the Test

The exact mass of loose-fill material needed to obtain the predetermined overall density in the test cell is weighed out. The weighed out material is divided into seven parts of equal mass. The mass of each part is given by Equation (1):

\[ m = \frac{\rho h \pi (\frac{1}{2}d)^2}{7} \]  

\[ (1) \]

where:

- \( \rho \) specified density of test specimen, kg/m³
- \( h \) height of loose-fill at test start, m;
- \( d \) internal diameter of test cell, m;
- \( \pi \) 3.14159

The parts are then placed one by one in the test cell in the following way. One part of the mass is homogeneously distributed over the horizontal plane of the cylinder and if necessary the tweezers can be used. When distributed, the stamper is gently used to press the mass to the predetermined density, marked on the test cell as a horizontal plane with marks at 3 angles (120°). When the mass is filled in the test cell, the piston is fixed with the sticks. Hereafter the test cell is stored at test start conditions for approximately one hour before continuing the test procedure. If loading with load discs with load hangers, these will be put in position followed by the displacement transducer. If i.e. nuts are used the displacement transducer is put in position.

7.4.2 Test Start

Recommended sampling is shown in table 1. Sampling must be started approximately 10 minutes before loading to get start position noted.

<table>
<thead>
<tr>
<th>Table 1. Recommended sampling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time from loading</td>
</tr>
<tr>
<td>0-2 h</td>
</tr>
<tr>
<td>2 h - end of test</td>
</tr>
</tbody>
</table>

When the start position is noted the test is ready to start. The low pressure is established and the piston is loosened and the rest of the load is mounted as weights on the upperside of the piston. Loading should not last longer than a few minutes. If loosening of the piston does result in an expansion of the mass, the piston must be unfixed first at the underside and then loaded before the sticks at the upperside of the piston are removed carefully.

7.4.3 Displacement

The vertical displacement of the piston is measured as a function of time, see Figure 3.

7.4.4 Change of Moisture Conditions

When the vertical displacement is small (showing a change in strain less than 0.04 % within the last 8 hours) the environment around the test set-up is changed according to the predetermined test history. The environment around the test set-up shall be established at the new environment within 8 hours. The test is finished for the vertical displacement of the piston to reached almost equilibrium exposed to the alternating moisture conditions (either showing a change in the strain state of equilibrium less that 0.8 % within the last 3 changes of the moisture conditions or showing an increase in the strain state of equilibrium less that 0.6 % within the last 3 changes of the moisture conditions).

7.4.5 Determine the Reference Density

When the test is finished the density at test start conditions is determined at a relative humidity of 50 % at 23 °C. The test cell is emptied and the mass of loose-fill material is conditioned and...
weighed. The reference density is given by Equation (2):

\[ \rho^{50\%23^\circ C} = \frac{m^{50\%23^\circ C}}{h\pi(\frac{1}{2}d)^2} \]  

(2)

where:

\[ m^{50\%23^\circ C} \] weight of the test specimen when conditioned to a relative humidity of 50 % at 23° C, kg;

### 7.5 Empirical Description of Strain

Find by the least squares method for each applied stress a linear function of logarithm of time given by Equation (3):

\[ \varepsilon(t) = p \ln(t/1 \text{ day}) + \varepsilon_1 \]  

(3)

where:

\[ t \] is time, days;

\[ p \] is a regression constant;

\[ \varepsilon_1 \] is a regression constant.

Test data that serves the objective of the test method describing the long-term strain behaviour of the material are used to find the linear functions of logarithm of time at each load level.

### 7.6 Determining Density

Determine the density of the loose-fill from the calculated strain at the time for which the density is to be described for each of the applied stresses from Equation (4):

\[ \rho_{\text{stress}(i)}^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} = \frac{m^{50\%23^\circ C}}{\left(h(1-\varepsilon(t))\pi(\frac{1}{2}d)^2\right)} \]  

(4)

where:

\[ \text{RH}_i, \text{RH}_u, \text{T}_i, \text{T}_u, n \] and stress(i) refers to the test history characterised by the set of parameters determining the minimum and maximum moisture exposure characterised by the relative humidity and the temperature, the number of cycles and the applied stress represented by \( i = 1, 2, 3, \ldots \), repetitions, respectively.

### 7.7 Empirical Description of Density

Find by the least squares method a linear function determining the density of the loose-fill as a function of the associated stress given by Equation (5):

\[ \rho^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} = k^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} \sigma + \rho_0^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} \]  

(5)

where:

\[ k^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} \] is a constant, kg/Nm;

\[ \rho_0^{\text{RH}_i, \text{T}_i, \text{RH}_u, \text{T}_u, n} \] is a constant, kg/m³;

\[ \sigma \] is the stress, N/m².

The stress is given by Equation (6):

\[ \sigma = \frac{q_{\text{total}}}{\pi(\frac{1}{2}d)^2} \]  

(6)

Where:

\[ q_{\text{total}} \] is the total load on the test specimen, including the low pressure established at the bottom plane and the load of the piston and weights and the measuring stick from the LVDT displacement transducer, N. The contribution from the low pressure is calculated as the low pressure multiplied by \( \pi(\frac{1}{2}d)^2 \).

### 7.8 Determination of Results

#### 7.8.1 Determination of Creep

Figure 3 shows the strain-time diagram for a mass of loose-fill cellulose fibre material applied a constant stress exposed to an alternating relative humidity. Alternating between the two constant environments described by a relative humidity of 50 % and 80 % at 23° C for a period of three to four days at a time. In addition a linear function of logarithm of time is found by the least squares method and shown for each of the 3 applied stresses. Test data from the fourth relative humidity cycle and on were used to find the linear functions of logarithm of time.

#### 7.8.2 Determining of Volume-stable State

Figure 4 shows the linear equation found by the least squares method describing density as a function of time and relative humidity cycles for the test data shown in Figure 3.
A period of 175 days corresponding to 25 relative humidity cycles was chosen to represent the strain for which creep has reached equilibrium for these experiments. From these assumptions the density for volume-stable state of the loose-fill as a function of the stress is calculated. By the least squares method $k_{RH_h,T_h/RH_l,T_l,n}$ and $\rho_{v-s,0}$ are found, $k_{50,23/80,23,25} = 0.0677$ kg/Nm and $\rho_{v-s,0} = 52.95$ kg/m³. v-s is used to indicate the state of the density for which the volume of the loose-fill material has become stable in time referred to as density for volume-stable state.

7.9 Limitations of the Method

It should be noted that strain found from applied low stresses could be erroneous because of the displacement transducer used and the assumption that the loss of stress from the top to the bottom of the mass is small related to the applied stress. Care should be taken to describe applied stresses, density at test start and test history related to the actual use of the loose-fill material.

7.10 Expression of Results

1. The results of the test are given as measured strain time curves shown including the applied part of the test data together with the adjusted linear function of logarithm of time clearly marked with the individual applied stress, temperature and relative humidity (test history) used.

2. A figure showing the linear function describing the density of the loose-fill material related to the volume of the loose-fill for which the creep has reached equilibrium as a function of the applied stress is issued. Furthermore, the chosen criterion to represent the strain is described.

3. Calculated values describing functions according to the applied stress and test history are registered together with the tested density of the loose-fill material.

4. Reference density.

5. It should be registered if any changes in appearance of the specimens during the test and any signs of degradation have been discovered, together with information on when the changes occurred and how big they are etc.

7.11 Accuracy

Note: Mathematical modelling of test results always has a degree of uncertainty and consequently the results have to be used with care.

7.12 Test Report

The test report shall include at least the following information:

a. Name and address of the testing laboratory
b. Identification number of the test report
c. Name and address of the organisation or the persons that ordered the test
d. Purpose of the test
e. Name and address of manufacturer or supplier of the tested object
f. Method of sampling and other circumstances (date and person responsible for the sampling)
g. Name or other identification marks of the tested object
h. Description of the tested object, the way in which they were mounted in the test apparatus and the used density.
i. Date of supply of the tested object
j. Test period
k. Duration of time and total number of test specimens for every noted applied stress specified by stress applied from test equipment and flexible stress
l. Conditioning of the test specimens, environmental data before and during the test (temperature, RH, etc.)
m. Identification of the test equipment and instruments used
n. Any deviations from the test method
o. Test results according to 7.10
p. Inaccuracy or uncertainty of the test result
q. Date and signature.

Note: Any results from test methods performed on fresh or aged materials/components may be included.

The test method is based on /1/ and shown used to determine the necessary density to prevent settling of loose-fill in wall cavities in /2/, /3/. 

30
Figure 1.  Apparatus to measure creep for loose-fill material. Top: vertical section. Bottom: plan. 1: 104.5 mm Ø: acrylic cylinder of 110 mm height. 2: 5.5 mm thick perforated acrylic plate. 3: 3 mm thick piston. 4: 10 mm marks. 5: sticks. 6: load disc. 7: load hangers. 8: bridge. 9: LVDT displacement transducer. 10: loose-fill material. 11: box. 12: flexible tube. 13: ventilator.
Figure 2. Photo of three test specimens in an ongoing test. The three test specimens are of equal mass mounted an individual load. Shown load is added as nuts. A low pressure has been established in the wooden box. A ventilator connected to the wooden box by the flexible tube to the right maintains the low pressure. The vertical displacement of each of the three pistons is measure using LVDT displacement transducers.
Figure 3. Strain-time diagram for loose-fill cellulose fibre material exposed to 23 °C and a relative humidity alternating between 50 % relative humidity and 80 % relative humidity and exposed to a constant stress of 83.12, 155.32 and 305.45 Pa, respectively. Functions found by the least squares method are shown.

Figure 4. The density for volume-stable state as a function of the applied stress. The linear function found by the least squares method is shown.
Figure 7. Diagram showing test results for CFI exposed to 23 °C and cyclic relative humidity alternating between 50 % and 80 % and exposed to external loads of 80.2, 150.0 and 300.5 Pa, respectively. Strain, relative humidity and temperature from tests carried out at Laboratory A are shown.
Figure 8. Diagram showing test results for CFI exposed to 23 °C and cyclic relative humidity alternating between 50 % and 80 % and exposed to external loads of 80, 150 and 300 Pa, respectively. Strain, relative humidity and temperature from tests carried out at Laboratory B are shown.
Figure 9. Diagram showing test results for CFI exposed to 23°C and cyclic relative humidity alternating between 50% and 80% and exposed to external loads of 77.7, 151.2 and 299.0 Pa, respectively. Strain, relative humidity and temperature from tests carried out at Laboratory C are shown.
Figure 10. Strain-time diagram for CFI with the density of 40 kg/m³ exposed to 23 °C and cyclic relative humidity alternating between 53 % and 83 % and exposed to external loads of 102, 204 and 408 Pa, respectively. Equations expressing strain as a linear function of logarithm of time at each load level are shown in pink bold lines. Laboratory D.
This report presents a proposal for a standardised method for creep tests and the necessary theoretical and empirical framework that can be used to describe creep of a granulated loose-fill material exposed to climate. Furthermore results from a round-robin test are shown. The round-robin test was carried out in collaboration with Norwegian Building Research Institute department of Materials and Structures in Trondheim, SP-Swedish National Testing and Research Institute department of Energy Technology, Building Physics, Ete in Boras, VTT-Technical Research Centre of Finland department of Building and Transport in Espoo and the Danish Building Research Institute department of Building Design and Technology. For the round-robin test a cellulosic fibre insulation material was used. The proposed standardised method for creep tests and theoretical and empirical framework are limited to cases when the granulated loose-fill material is exposed to a climate that is characterised as cyclic humidity conditions (a constant temperature and a relative humidity alternating between two predetermined constant relative humidity levels).

A better understanding of the behaviour of granulated loose-fill material is provided and a standardised method is proposed. This enables control of the settling and prediction of densities necessary to prevent settling. The Nordtest, Organisation for Testing in Scandinavia funded the Nordtest Project 1623-03.

1st edition, 2005
ISBN 87-563-1222-9

The project was funded by Nordic Innovation Centre.