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Creep of granulated loose-fill insulation

Test method and round robin test

Nordtest project 1536-01

BY OG BYG
Statens Byggeforskningsinstitut
Danish Building and Urban Research

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Foreword

This report presents a proposal for a standardised method for creep tests and the necessary theoretical framework that can be used to describe creep of a granulated loose-fill material. Furthermore results from a round robin test are shown.

The project was carried out because granulated insulation materials that are loose-filled in 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 is proposed. This enables control of the settling and prediction of densities necessary to prevent settling.

Nordtest has funded the project (Nordtest project 1536-01).

By og Byg, Danish Building and Urban Research
Building Technology and Productivity Division
July 2002

Jørgen Nielsen
Head of division

Introduction

Background

It is well known that granulated insulation materials that are loose-filled in walls may settle after installation. For example, loose-fill insulation in a test house with wood frame walls with gypsum boards exhibited progressive settling between 0.07 and 0.38 m, before and after removal of the gypsum board that was acting as a wind barrier, (Andersen *et al.,* 2000).

Today, when used for insulation in attics, an extra amount of loose-fill insulation is added, over and above the level required for insulation, as a solution to the settling problem. When used in walls, settling is neutralised by adding insulation with a higher density. So far, this higher density has been based on experience.

In order to control the settling, or to be able to predict densities necessary to prevent settling of 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 granulated loose-fill insulation material in walls, (Rasmussen 2002).

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. In addition a round robin test of the proposed experimental techniques and the theoretical framework needed for determining the associated creep parameters were described.

Test material

The tested loose-fill material was a granulated loose-fill cellulose-based material made of recycled paper and used for thermal insulation. The test material was Ekofiber vind from the Swedish manufacturer Nordiska Ekofiber NEF AB, Kallinge o Pilgrimstad, Sweden. In the following it is referred to as cellulose fibre insulation (CFI). A similar granulated loose-fill cellulose-based material was introduced by SP. In the following it is referred to as cellulose fibre insulation SP (CFI-SP). CFI is made from recycled paper torn into pieces of approximately 2 mm by 3 mm. In total, 16 % 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 parts were not bound together in a fixed predefined form. With a relatively small effort, the CFI could be distributed homogeneously across a predefined area that 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 necessary theoretical framework that can be used to describe creep of a granulated loose-fill material. The proposed standardised method for creep tests and theories are limited to cases where the granulated loose-fill material is exposed to a constant environment with a constant temperature and a constant relative humidity.

Tests

The proposed creep test and its related theoretical framework has been tested in a round robin test. The round robin test was carried out in collaboration with SP-Building Physics in Sweden and VTT Building Technology in Finland.

Tests in the round robin test were carried out at a constant temperature of 23 °C and a relative humidity (RH) of 50 %. The round robin test program included three test series, each test series described by its density. For each density three identical specimens of cellulosic fibre insulation were tested by exposure to a stress state of respectively 78, 202 and 499 Pa. The densities of the three test series were 42, 50 and 60 kg/m^3.

In addition, additional tests were carried out at a constant temperature of 23 °C and a relative humidity of either 50 % or 80 % at By og Byg. One test series with a density of 30 kg/m^3 was carried out at a relative humidity of 50 %. Two test series with a density of 42 and 50 kg/m^3 were carried out at a relative humidity of 80 %.

Conclusion

It was found to be possible to describe creep analytically and in good agreement with test results. Test results were produced at VTT Building Technology, Finland and By og Byg. Test results from SP-Building Physics, Sweden have not been used. The material tested by SP-Building Physics, Sweden was replaced by a product different from the one tested at VTT Building Technology, Finland and By og Byg.

CFI can be defined as Clouser materials, and analyses of the creep function shows that the material behaviour can be described by the Clouser equation. Stress components determined using the description of the creep function by means of the Clouser equation were found to be in good agreement with strain components determined from the strain-time diagram.

The elastic modulus is the linear elastic modulus and represents the capability of the material to regain its volume when relieved of its load. The elastic modulus was determined from the strain-time diagram. The elastic modulus was found to be independent of the density. However the consolidation increased with decreasing density.

Future recommendations

CFI is normally used as an insulation material and will therefore normally be exposed to changing relative humidity. CFI exposed to changing relative

humidity is not covered by the proposed standardised method for creep tests.

Strain-time behaviour for CFI exposed to an alternating relative humidity have been investigated and results are shown in (Rasmussen 2002). These investigations have shown that for CFI exposed to a constant load and an alternating relative humidity the strain-time diagram shows a progressive strain. Stabilisation of the progressive strain is indicated after a few cycles.

Because strain behaviour related to an alternating relative humidity is the most important material behaviour when determining settling of granulated loose-fill materials used as insulation, it is recommended that a test method is formulated and proposed to determine stress-time diagrams for granulated loose-fill materials used as thermal insulation and exposed to an alternating relative humidity.

Theory

Creep of materials

A material under instantaneous load will be subject to instantaneous strain, and under a 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 the 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).

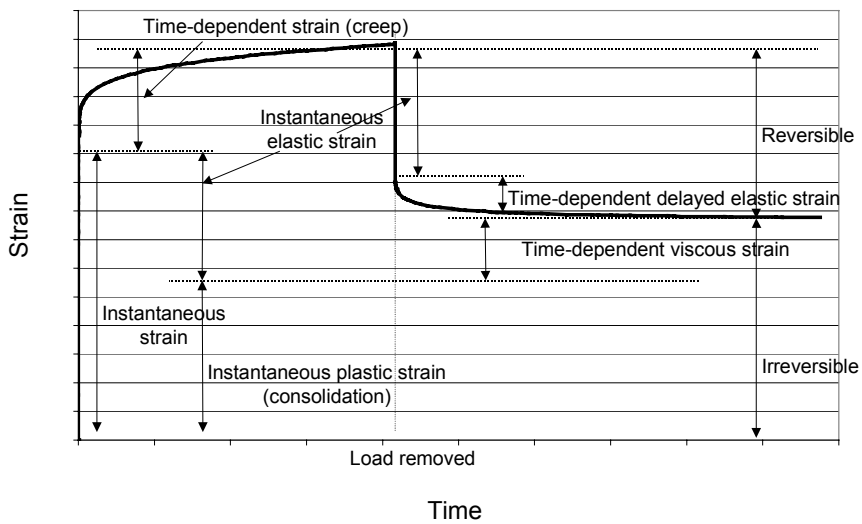

Figure 1. Typical example of creep as a function of time for a material with a constant load that is subsequently removed.

Theoretical description of creep

Creep and recovery can be described theoretically by applying the theory for a so-called Burgers material (Flügge, 1967; Nielsen, 1972; Fuglsang Nielsen, 1973; Wesche, 1977). The Burgers model is known as being the most complex of the simpler models describing creep. Moreover, it is a model that can be used to describe the strain phenomena that characterise a viscoelastic material; the pure elastic component, the pure viscous component, and the delayed elastic component (Fuglsang Nielsen, 1986). A theoretical description of the creep function can be used to determine parameters to describe the theoretical relaxation.

In addition, some materials can also be defined as Clouser materials, and can be described by the simpler Clouser equation (Clouser, 1959). Use of the Clouser equation is recommended if the analysis of the creep function permits. It should also be noted that parameters of the creep functions are

theoretically independent of the load state. However, this is true only if the load does not cause damage to the material.

The creep function that describes the creep (and relaxation) of a Burgers material (Burgers 1935) is given by the following equation, e.g. Fuglsang Nielsen (1988):

$$c(t) = \frac{1}{E} + \frac{1}{\eta}t + \frac{1}{E_{\mathrm{k}}}\left(1 - \mathrm{e}^{-\delta_{\mathrm{k}}t}\right) \qquad (1)$$

where t (s) is time, E (Pa) and E_{k} (Pa) are elastic moduli, η (Pa·s) is viscosity and δ_{k} (s^{-1}) is a rheological constant given by $\delta_{\mathrm{k}} = E_{\mathrm{k}}/\eta_{\mathrm{k}}$ where η_{k} (Pa·s) is viscosity.

The creep of a Clouser material is given by the following equation (Fuglsang Nielsen 1986, 1993):

$$c(t) = \frac{1}{E}\left[1 + \left(\frac{t}{\tau}\right)^{a_1}\right] \qquad (2)$$

where τ (s) is a constant called the relaxation time and a_1 (dimensionless) is the creep exponent which is also a constant.

The creep function, $c(t)$ describes the strain that appears when the mass at the time t = 0 is applied a constant stress, σ = 1. The value of the starting point is $c(0) = 1/E$.

With a good approximation the relaxation function corresponding to the Clouser creep function above can be described by the following equation (Fuglsang Nielsen 1986, 1993):

$$r(t) \approx \frac{1}{c(t)} = E\left[1 + \left(\frac{t}{\tau}\right)^{a_1}\right]^{-1}. \qquad (3)$$

The measured creep that develops in the mass exposed to constant stress as a function of time is adjusted to the Clouser equation. Adjusting the creep data to the Clouser equation it is found that the equation can be linear by logarithm in the following way:

$$Y = Y_0 + \alpha X \qquad (4)$$

where

$$Y = \log_{10}\left(Ec(t) - 1\right) \qquad (5)$$

$$X = \log_{10} t \qquad (6)$$

$$Y_0 = -a_1 \log_{10} \tau \qquad (7)$$

$$\alpha = a_1 \qquad (8)$$

here X_0 is found by using

$Y = 0$ which gives

$$X_0 = -\frac{Y_0}{\alpha} \qquad (9)$$

and a_1 and τ can be determined as

$$a_1 = \alpha = -\frac{Y_0}{X_0} \qquad (10)$$

$$\tau = 10^{-Y_0/\alpha} = 10^{X_0} \qquad (11)$$

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.

Tests in the round robin test were carried out at a constant temperature of 23 °C and 50 % RH. The round robin test program included three test series, each test series described by its density. For each density three identical specimens of CFI were tested by exposure to a stress state of respectively 78, 202 and 499 Pa. The densities of the three test series were 42, 50 and 60 kg/m^3.

In addition, additional tests were carried out at a constant temperature of 23 °C and a relative humidity of either 50 % or 80 % at By og Byg. One test series with a density of 30 kg/m^3 was carried out at 50 % RH. Two test series with a density of 42 and 50 kg/m^3 were carried out at 80 % RH. Results from these tests are shown and used in the discussion of the test method.

Results

The round robin test was carried out in collaboration with SP-Building Physics, Sweden and VTT Building Technology, Finland. The test report from SP-Building Physics, is shown in Appendix C and the test report from VTT Building Technology, is shown in Appendix E. Strain-time diagrams from tests carried out at By og Byg are shown in Appendix B. In the following test results from By og Byg are shown.

Creep tests

Creep was described for a number of combinations of various densities, and different moisture contents for CFI. Creep is defined as the strain that occurs in a material exposed to a constant load over a period of time. Consolidation is not defined as creep (Nielsen, 1972; Hagemann, 1989; Fuglsang Nielsen, 1986, 1993; Rasmussen, 2001a, 2001b). The following data can also be seen in (Rasmussen 2001b).

Figure 2 shows the strain-time diagram for CFI with a density of 50 kg/m^3 filled into the test equipment; it was exposed to a constant stress of 499 Pa until the time denoted t_1 and subsequently relieved of 87 % of its stress. The test was carried out at 23 °C and 50 % RH.

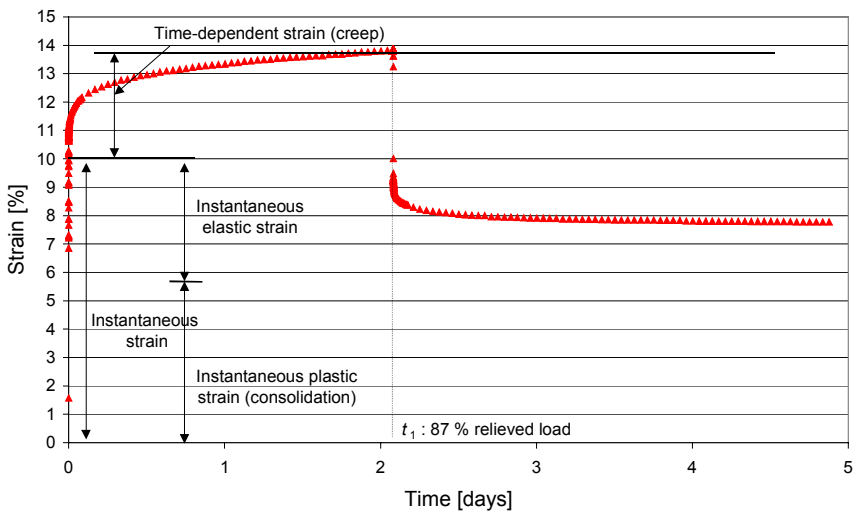

Figure 2. Strain-time diagram for CFI, which was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load.

Table 1 shows strain components determined from strain-time diagrams for CFI. Table 1 includes the measured instantaneous strain, measured instantaneous elastic strain determined from the stress relief at the time t_1 and instantaneous plastic strain, also denoted consolidation. The instantaneous plastic strain is defined as the difference between the instantaneous strain and the instantaneous elastic strain.

Strain-time diagrams were determined for CFI of various densities filled into the test equipment and exposed to a constant stress of 78, 202 and 499 Pa, respectively until the time denoted t_1, and subsequently relieved of 20, 68 and 87 % of its stress. CFI tests were carried out with densities of 30, 42, 50 and 60 kg/m^3 at 23 °C and 50 % RH. Additionally, tests were carried out with densities of 42 and 50 kg/m^3 at 23 °C and 80 % RH. The nominal density is the density of the insulation material at 23 °C and 50 % RH.

Table 1. Strain components determined from CFI with densities of 30, 42, 50, and 60 kg/m^3 at 23 °C and at 50 % RH and 80 % RH.

Relative humidity [%]		50				80	
density [kg/m^3]		30	42	50	60	42	50
Strain	Stress level [Pa]						
Instantaneous strain	78	0.092	0.062	-0.010	-0.068	0.060	-0.008
	202	0.201	0.131	0.010	-0.018	0.120	0.004
	499	0.307	0.22	0.100	0.038	0.210	0.060
Instantaneous elastic strain	78	0.005	0.003	0.003	0.010	-	-
	202	0.020	0.021	0.022	0.022	0.010	0.008
	499	0.047	0.056	0.054	0.057	0.019	0.022
Instantaneous plastic strain (consolidation)	78	0.088	0.059	-0.013	-0.078	0.060	-0.008
	202	0.181	0.110	-0.012	-0.040	0.110	-0.004
	499	0.260	0.164	0.046	-0.019	0.192	0.038

The elastic modulus was determined from the measured instantaneous elastic strain determined from the load relief at the time t_1. Table 2 shows the elastic modulus for CFI at densities of 30, 42, 50 and 60 kg/m^3 at 23 °C and at 50 % RH and 80 % RH. The elastic modulus was determined from the two highest stress levels. The elastic modulus is the linear elastic modulus and represents the capability of the material to regain its volume when relieved of its load.

Table 2. Elastic moduli (average of the two highest stress levels) for CFI at densities of 30, 42, 50 and 60 kg/m^3 at 23 °C and at 50 % RH and 80 % RH.

Density [kg/m^3]	RH [%]	Elastic modulus [Pa]
30	50	10,690
42	50	8,650
50	50	9,850
60	50	9,900
42	80	31,330
50	80	29,385

Adjusting the creep data

An extract of the measured creep data, for at least three load levels, was adjusted to the linear logarithm creep equation by the method of least squares. The elastic modulus used was the average instantaneous elastic modulus found from unloading.

Figure 3 shows the determination of creep parameters for CFI from measured strain-time data. The strain-time data shown are from CFI with a density of 50 kg/m^3 at 50 % RH and 23 °C.

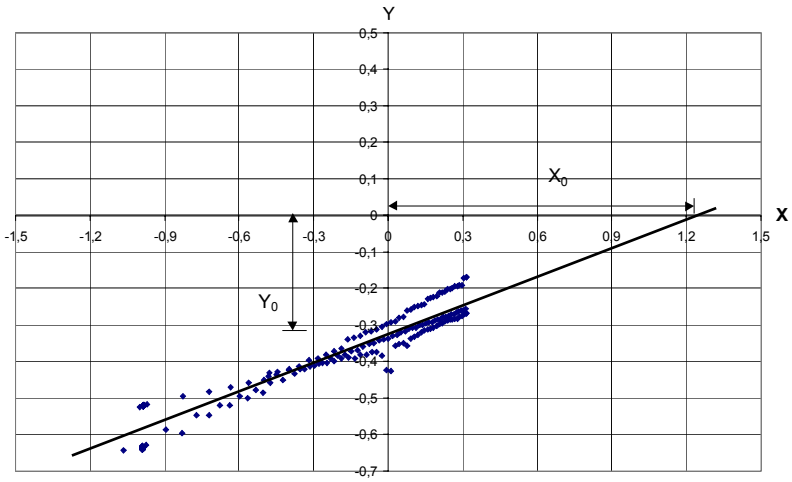

Figure 3. Determination of creep parameters for CFI with a density of 50 kg/m^3 at 50 % RH and 23 °C from measured strain-time data.

Table 3 shows the creep parameters a_1 and τ describing the Clouser equation for CFI at different densities and different moisture conditions. Furthermore, the strain components used are shown. The creep data were adjusted to the Clouser equation for the stress levels of 78, 202 and 499 Pa. Creep tests were carried out for the densities of 30, 42, 50 and 60 kg/m^3 at 23 °C and 50 % RH. Additional tests were carried out with the density of 42 and 50 kg/m^3 at 23 °C and 80 % RH.

Table 3. Creep parameters and strain components used for CFI at densities of 30, 42, 50 and 60 kg/m^3 at 23 °C and at 50 % RH and 80 % RH.

RH [%]		50				80	
Density [kg/m^3]		30	42	50	60	42	50
a_1		0.2563	0.2759	0.2612	0.1345	0.3118	0.3317
τ [days]		0.0723	1.9015	17.4566	139.6309	0.0025	0.0215
Strain	Stress level [Pa]						
Instantaneous strain	78	0.1100	0.0670	-0.0140	-0.0790	0.0850	-0.0120
	202	0.2200	0.1400	0.0130	-0.0280	0.1450	0.0065
	499	0.2700	0.2200	0.1100	0.0280	0.2000	0.0670
Instantaneous elastic strain	78	0.0073	0.0093	0.0080	0.0079	0.0025	0.0027
	202	0.0190	0.0243	0.0205	0.0204	0.0065	0.0069
	499	0.0467	0.0598	0.0508	0.0505	0.0159	0.0170
Instantaneous plastic strain (consolidation)	78	0.1027	0.0577	-0.0220	-0.0869	0.0825	-0.0147
	202	0.2010	0.1157	-0.0075	-0.0484	0.1385	-0.0004
	499	0.2233	0.1602	0.0592	-0.0225	0.1841	0.0500

The Clouser equation describing the creep of CFI with a density of 50 kg/m^3 at 23 °C and 50 % RH is shown in Figure 4. Strain was calculated using equation (2) with E = 9850 MPa, a_1 = 0.2612 and τ = 17.4566 days. ε_0 is taken from Table 3 according to stress level. CFI was exposed to constant stresses of 78, 202 and 499 Pa until the time denoted t_1 and subsequently partly relieved of 20, 68 and 87 % of its load, respectively. The Clouser equation is depicted by a solid line. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively. The Clouser equation describing the creep of CFI after the time denoted t_1 is described by means of the superposition principle. Additional strain-time diagrams from tests carried out at By og Byg are shown in Appendix B.

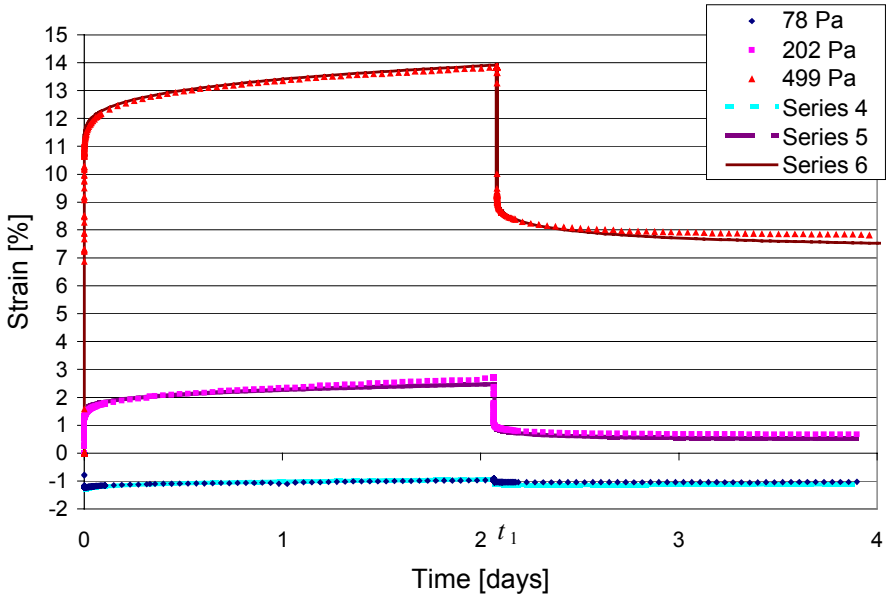

Figure 4. Strain-time diagram for CFI. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

Discussion

It was suggested that the round robin test should start with reading, comment on and clarifying of the proposal for the standardised method for testing and modelling of creep. Hereafter the actual test and calculations should take place. Regrettably, this procedure was not followed which is why SP-Building Physics, Sweden had to make additional tests and subsequently ran out of CFI material. CFI was replaced by a similar product from the same manufacturer (CFI-SP). Unfortunately, it became clear at a very late stage that CFI-SP was obviously different both in appearance and behaviour from CFI. SP-Building Physics, Sweden did, however, carry out tests using another sampling procedure than described in the proposal for the standardised method.

VTT Building Technology, Finland carried out the tests using the proposed method.

The strain-time components of CFI exposed to a constant load and constant moisture conditions have been shown. CFI can be defined as Clouser materials, and analyses of the creep function permit CFI to be described by the Clouser equation, see Figure 4 and Figure 5 to Figure 9 in Appendix B and Figure 1a to Figure 3b, Appendix E. Strain components determined using the Clouser equation was found to be in good agreement with strain components determined from the strain-time diagram, see Table 1 and Table 3. It was also found that parameters describing the creep functions are theoretically independent of the load level. However, this is only true if the load does not cause damage to the material. Additional tests have shown that CFI, woodwool, granulated flax and granulated mineral wool can be defined as Clouser materials, (Rasmussen, 2001b).

The elastic modulus is the linear elastic modulus and represents the capability of the material to regain its volume when relieved of its load. The elastic modulus was determined from the strain-time diagram. The capability of the material to regain its volume was shown to be related to the relative humidity of the CFI. For the actual investigated densities of CFI, the capability of the material to regain volume decreased by approximately 33 % with an increase of the relative humidity from 50 % to 80 %. Similar results are seen for other types of organic materials, see Rasmussen (2001b). Furthermore, it is demonstrated that the capability of the material to regain its volume is not related to the CFI density examined in this investigation, see Table 2.

Parameters describing the creep functions for tests carried out at VTT Building Technology, Finland are given in Table 1, in Appendix E. The determined elastic modulus is seen to be somewhat higher than that of experiments carried out at By og Byg. However the subsequent determination of creep parameters are overall in good agreement with parameters found by By og Byg. The less good agreement in determining the constant parameter called the relaxation time is believed to bee related to the determination of the elastic moduli. The elastic modulus is to be found from measurements of when the displacement for the determination of removing a high percentage of the added load. Determination of the elastic modulus is discussed in the proposed standardised method, see Appendix A section 6.6.

SP-Building Physics, Sweden did not carry out the calculations. Calculations have been carried out by By og Byg, se Appendix D. The Clouser equation and the matching strain-time measurements of CFI-SP with the density 42 kg/m^3 are given in Appendix D. The Clouser equation is depicted by a solid line. The Clouser equation for the stress levels starting at 78.9,

200.1 and 498.5 Pa is denoted series 4, series 5 and series 6, respectively. The Clouser equation describing the creep of CFI-SP after the time denoted t_1 is described by means of the superposition principle. Additionally, results from a test of CFI-SP with the density 42 kg/m^3 for the stress level 200.1 Pa carried out at SP-Building Physics, Sweden and By og Byg is shown in Appendix D. These tests demonstrate the need for a definition of the time from mounting the material and test start. The time interval is included in the proposed method.

CFI is usually used as an insulation material and will therefore normally be exposed to changing relative humidity. Here CFI exposed to an alternating relative humidity have been investigated and results are shown in (Rasmussen 2002). These investigations have shown that for CFI exposed to a constant load and an alternating relative humidity the strain-time diagram show a progressive strain. Stabilisation of the progressive strain was indicated after a few cycles, (Rasmussen 2002). This phenomenon is not covered by the test method proposed. However, strain behaviour related to an alternating relative humidity is the most important material behaviour when determining settling of granulated loose-fill materials used as insulation. It is therefore recommended that a new round robin test should be established to describe a test method for determining stress-time diagrams of granulated loose-fill materials used as thermal insulation exposed to an alternating relative humidity.

Conclusion

This report presents a proposal for a standardised method for creep tests and theories that can be used to describe creep of a granulated loose-fill material. The proposed creep test and related theoretical framework have been tested in a round robin test. The round robin test was carried out in collaboration with SP-Building Physics, Sweden and VTT Building Technology, Finland. The proposed standardised method for testing and modelling of creep is carried out at a constant temperature and a constant relative humidity. The report shows methods for determining relevant material behaviour to determine strain-time components to be able to describe creep of granulated loose-fill material.

It was found to be possible to determine creep analytically in good agreement with test results. However, the round robin test did not attain its purpose and test results from SP-Building Physics, have not been used in the discussion. The material tested by SP-Building Physics, Sweden was replaced by a similar product from the same manufacturer obviously different both in appearance and behaviour from the one tested by VTT Building Technology, Finland and By og Byg.

Granulated loose-fill material used as thermal insulation can be defined as Clouser materials, and analyses of the creep function shoes that it is possible to describe the mechanical behaviour of the material with the Clouser equation. Stress components determined using the description of the creep function given by the Clouser equation was found to be in good agreement with strain components determined from the strain-time diagram. It was also found that the parameters describing the creep functions are theoretically independent of the load level. However, this is only true as long as the load does not cause damage to the material.

The elastic modulus is the linear elastic modulus and represents the capability of the material to regain its volume when relieved of its load. The elastic modulus was determined from the strain-time diagram. The elastic modulus was found to be independent of the density. However the consolidation increased with decreasing density.

References

Andersen T., & Skibstrup Eriksen S. (2000). *Alternativ isolering i bygninger* (SBI-meddelelse 128). Hørsholm: Statens Byggeforskningsinstitut.

Burgers, J. M. (1935). Mechanical considerations, model systems, phenomenological Theories. In *First report on viscosity and plasticity*, (pp. 21-33). Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen.

Clouser, W. S. (1959). *Creep of small wood beams under constant bending load* (Report 2150). Madison, WI: U.S. Forest Products Laboratory.

Flügge, W. (1967). *Viscoelasticity*. Waltham, MA: Blaisdell.

Fuglsang Nielsen, L. (1973). Rheologische Eigenshaften für isotrope linear-viskoelastische Kompositmaterialien. *Cement and Concrete Research*, (3), 751.

Fuglsang Nielsen, L. (1986). *Materialemekanik: Grundkursus II i bygningsmaterialer* [Materials mechanics] (Technical Report 169) Lyngby: Technical University of Denmark, Building Materials Laboratory.

Fuglsang Nielsen, L. (1988). *Materialemekanik II: Rheologi, brud, kompositmaterialer og levetid* [Materials mechanics II. Rheology, fracture, composite materials and life time] (Teknisk Rapport 189). Lyngby: Technical University of Denmark, Building Materials Laboratory.

Fuglsang Nielsen, L. (1993). *Materialemekanik* [Materials mechanics] (Technical Report 286). Lyngby: Danmarks Tekniske Højskole, Laboratoriet for Bygningsmaterialer.

Hagemann, E. (1989). *Byggematerialer: Grundbog* (5. udg.) [Building materials]. København: Polyteknisk Forlag.

Nielsen, A. (1972). *Rheology of building materials*. Stockholm: National Swedish Building Research.

Rasmussen, T. V. (2001a). Modelling settling of loose-fill insulation in walls. Part I. *Journal of Thermal Envelope and Building Science, 25*(October), 129-141.

Rasmussen, T. V. (2001b). *Sætningsfri indblæsning af løsfyldsisolering i vægge* [Settling of loose-fill insulation materials in walls] (By og Byg Dokumentation 011). Hørsholm: Statens Byggeforskningsinstitut.

Rasmussen, T. V. (in press). Creep tests and techniques for predicting densities necessary to prevent settling of loose-fill insulation in walls. Accepted for publication in A. O. Desjarlais (Ed.), Insulation materials: Testing and applications: Vol. 4 (ASTM STP 1426). West Conshohocken, PA: American Society for Testing and Materials, ASTM.

Wesche, K. (1977). Baustoffe für tragende Bauteile. In K. Wesche, H. R. Rainer, & I. Schrage, *Baustoffe für tragende Bauteile. Bd.1. Baustoffkenngrössen, Messtechnik, Statistik* (pp. 68-84). Wiesbaden: Bauverlag.

Sammenfatning

By og Byg Dokumentation 028: Løsfyldsisoleringsmaterialers krybning.

Ringprøvning

I denne rapport præsenteres et forslag til en testmetode og dertil hørende teori, hvorefter krybningen for et løsfyldsmateriale kan bestemmes. Testmetode og teori begrænser sig til det tilfælde, hvor løsfyldsmaterialet er udsat for et konstant klima med konstant temperatur og konstant relativ luftfugtighed.

Det præsenterede forslag, til en testmetode og den dertil hørende teori, er blevet afprøvet ved en samkalibrering foretaget i samarbejde med SP-Building Physics i Sverige og VTT Building Technology i Findland.

Samkalibreringen blev udført under et konstant klima med en konstant temperatur på 23 °C og under en konstant relativ luftfugtighed på 50 %. Samkalibreringen blev udført med et løsfyldsisoleringsmateriale af cellulose. Endvidere indeholder rapporten resultater fra en udvidet testserie foretaget på By og Byg. Den udvidede testserie indeholder resultater udført under en konstant temperatur på 23 °C og for en konstant relativ luftfugtighed på 80 %.

Samkalibreringen viste, at det er muligt at bestemme materialets krybning analytisk i god overensstemmelse med de udførte forsøg.

Forsøgene viste, at løsfyldsisoleringsmateriale af cellulose kan karakteriseres som Clouser materialer, og kan derfor beskrives ved Clouser funktionen. Samkalibreringen viste en god overensstemmelse mellem Clouser funktionen og den tidsafhængige krybning for løsfyldsisoleringsmateriale af cellulose, fundet ved forsøg.

Elasticitetsmodulet for løsfyldsisoleringsmaterialet er karakteriseret som det lineære elasticitetsmodul og beskriver materialets evne til at genvinde sit volumen ved aflastning. Elasticitetsmodulet er vist at være uafhængig af densiteten medens konsolideringen er stigende for faldne densitet.

Appendix A

LOOSE-FILL INSULATION IN WALLS

TESTING AND MODELLING OF CREEP

LOOSE-FILL INSULATION IN WALLS

- TESTING AND MODELLING OF CREEP

(Based on By og Byg Documentation 011, "Sætningsfri indblæsning af løsfyldsisolering i vægge", Danish Building and Urban Research, 2001)

2002 06 12

Key words: Loose-fill material, insulation, creep, model, test method

1. SCOPE

This NORDTEST method specifies a method for describing creep for loose-fill material used as insulation in walls. The method consists of a test method and a technique that can be used to adjust test results to a model.

The method seeks to model creep in a loose-fill material influenced by and in balance with a stable environment.

It is the objective to use tests to model and describe long-term material behaviour using a much shorter test period. Consequently, the method is a distinct short-term test.

2. FIELD OF APPLICATION

The method has been specially designed to describe and model the creep behaviour of loose-fill materials. The method is designed for use in the laboratory.

3. REFERENCES

Nielsen, L. F. (1986). Materialemekanik grundkursus II i bygningsmaterialer (Materials mechanics; in Danish), Technical Report 169/86, Building Materials Laboratory, Technical University of Denmark.

Nielsen, L. F. (1988). Materialemekanik II Rheologi, brud, kompositmaterialer og levetid (Materials mechanics II. Rheology, fracture, composite materials and durability; in Danish), Technical Report 189/1988, Building Materials Laboratory, Technical University of Denmark.

Nielsen, L. F. (1993). Materialemekanik (Materials mechanics; in Danish), Technical Report 286/1993, ISSN 0908-3871, Building Materials Laboratory, Technical University of Denmark.

Rasmussen T. V. (2001). Sætningsfri indblæsning af løsfyldsisolering i vægge, By og Byg Documentation 011, Danish Building and Urban Research.

Rasmussen T. V. (2001). Modelling Settling of Loose-Fill Insulation in Walls. Part I, Journal of Thermal Envelope & Building Science, Vol. 25, No. 2, October 2001.

Rasmussen T. V. (2002). Modelling Settling of Loose-fill Insulation in Walls, Part II, Determination of Coefficients, Journal of Thermal Envelope & Building Science, Vol. 25, No. 3, January 2002.

Rasmussen T. V. (2002). Creep Tests and Techniques for Predicting Densities Necessary to Prevent Settling of Loose-fill Insulation in Walls, submitted for publication in *Insulation Materials: Testing and Aplications: 4th Volume, ASTM STP1426*, A. O. Desjarlais, Ed., American Society for Testing and Materials, West Conshohocken, PA.

4. DEFINITIONS

Loose-fill material is defined as a mass of material that contains a lot of minor separate parts of the material. These minor parts are not bound together in a fixed predefined form. By small means the mass can be distributed homogeneously across a predefined area, large compared with the size of a single particle.

Creep is defined as the strain that occurs in a material exposed to a constant load as a function of time. Consolidation seen as part of the instantaneous strain during loading is not defined as creep.

5. SAMPLING

Samples should be randomly chosen. The chosen sample is loosened by pressurised air in a closed box mounted a vent that prevents loss of material before tested. Furthermore, the sample must be conditioned to test conditions before testing. Especially conditioning for the predetermined relative humidity and the predetermined temperature is important. The sample should be handled in such a way that the least possible interaction of particles, moisture and additives with the surroundings takes place.

The minimum amount of test specimens is 3 samples of equal weight.

As far as possible a sufficient number of specimens should be exposed as to allow for statistical examination of the results.

6. TEST METHOD

Constant environment

6.1 Principle

Rheology, as a concept of a material, contains every relation between stress, strain and time. In rheology the creep function of a material is of great importance. Experimentally the creep function is determined by measuring the strain as a function of time for a material exposed to constant stress.

The height of the sample is kept limited so that the loss of stress from the top to the bottom of the mass is unimportant in relation to the measured displacements.

Displacements are measured along the vertical centreline of the loose-fill material.

6.2 Apparatus

Apparatus for creep test includes the following:

Test container. An acrylic cylinder with a vertical centreline is mounted on a horizontal acrylic plate. The cylinder has an internal diameter of 104.5 mm ± 0.5 mm and is approximately 110 mm in height. The test container also consists of at plane disc made of acrylic with a diameter 1.5 - 2 mm less than the internal diameter of the cylinder. The plane disk is provided with small drilled not riddled drilled holes made for grips. The plate is approximately 5.5 mm thick, and the cylinder and the disc are both approximately 3 mm thick. 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 disc is to be fixed in a position where the distance from the bottom to the underside of the disc is 70 mm. This can be done by sticks put through holes drilled in the cylinder.

Weights that should be easy to add to and remove from the upperside of the disc introducing only minor disturbance and source of error to the test. The load is to be mounted as a steady load on top of the disc. For heavier loads it would be a good idea to use load discs with load and off-load hangers.

Mounting-stick. An approximately 200 mm stick is mounted perpendicular to a disk. The diameter of the disk is 1.5 - 2 mm less than the internal diameter of the cylinder. The disk is provided with a 1 - 1.5 mm in diameter hole for every cm^2. The disc is made of acrylic and is approximately 5.5 mm thick.

A distance measuring system with the capability of at least 12 mm of displacement with an accuracy of ± 0.1 mm. For example a LVDT displacement transducer mounted on a bridge that can be mounted on top of the cylinder. The position of the displacement transducer should be flexible. The weight of the displacement transducer stick is included in the load put on the mass.

A data logger 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 and a light form of respirator should be used together with tweezers and containers for handling and storing the material.

Tests should be carried out in an environment where the relative humidity and temperature are to be kept constant with an accuracy of ± 2% and ± 2 ^{o}C, respectively.

Apparatus and a test set-up are shown in figure 1.

6.3 Preparation of Test Specimens

Prior to exposure, information about the test specimens is registered, e.g. manufacturer, identification (name and type), production method, date of sampling, observations and measurements.

The test specimens are kept in the conditions specified by the supplier until test preparations are carried out.

The test container and the mounting-stick are washed in soap and warm water (approximately 35 ^{o}C) and afterwards flushed out with distilled water before being dried lightly with a paper towel and finally air dried.

Test equipment must be clean and non-static electric.

All test equipment and the lose-fill material are conditioned before testing.

6.4 Procedure

The right amount of loose-fill material in order to obtain the predetermined overall density in the test container is weighed. The weighed material is divided into seven parts weighing the same. The parts are then mounted one by one in the test container 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 mounting-stick is gently used to press the mass to the predetermined density, marked on the test container as a horizontal plane with spots at 3 angles (120°). When the mass is filled in the test container, the disc is fixed. Hereafter the test container is stored for approximately one hour before continuing the test procedure.

If loading with load hangers is used, these will hereafter be put in position. Furthermore, the displacement transducer is put in position.

The test is then ready and logging can take place. When the start position is noted, the disc is loosened and the predetermined load is mounted on the upperside of the disc. Loading should not last longer than 20 seconds. If loosening of the disc does result in an expansion of the mass, the disc must be unfixed first at the underneath and then loaded before the sticks at the upperside of the disc are removed carefully.

Logging time is recommended to start with a time difference of 1 second increasing to 5 seconds a few minutes after loading, increasing stepwise to 1 hour after 2 hours from the time of loading.

The vertical displacement of the disc is measured as a function of time. After some time, for example 3 days, the added load is carefully removed and hereafter the disc and the displacement transducer stick will only load the mass. When unloading it is recommended to use the logging time as described above. The test is finished 2 hours after the removal of a part of the load.

It is important to hold the test set-up vibration free during the test period.

Test specimens exposed simultaneously must not be able to influence each other.

One test series includes 3 in principle identical specimens of loose-fill mounted 3 independent load cases.

The mounting procedure of the test specimens in the apparatus will be described in the report.

Any signs of degradation are noted e.g. voids, lumps, delamination etc. during exposure.

6.5 Theoretical Description of Creep

Creep can be described theoretically by applying the theory for a Burger material, (Nielsen 1988). Creep can be determined with the use of a theoretical description of the creep function. In addition, some materials can also be defined as Clouser materials, and can be described by the simpler Clouser equation. Use of the Clouser equation is recommended if the analysis of the creep function permits.

It is noted that parameters in the creep functions are theoretically independent of the load state. However, this is only true if the load does not cause damage to the material.

The creep of a Clouser material is given by the following equation (Nielsen 1986, 1993):

$$c(t) = \frac{1}{E}\left[1 + \left(\frac{t}{\tau}\right)^{a_1}\right]$$

where

t is time

E (Pa) is the elastic module

η (Pa·s) is viscosity

and δ (s^{-1}) is a rheological constant given by

$$\delta = \frac{E}{\eta}$$

$\tau = \frac{1}{\delta}$ is a constant termed the relaxation time (s)

and

a_1 (dimensionless) is the creep exponent which is also a constant.

The creep function $c(t)$ describes the strain that occurs, for the material to be exposed to a constant stress, σ=1 at the time t=0.

6.6 Determination of the Creep Function

The theoretical description of the creep function can be used to describe the time dependent strain. Instantaneous strain contains an instantaneous elastic part and an instantaneous plastic part. The

instantaneous plastic strain must be added to the creep function as a constant and take therefor no part in the determination of the parameters a_1 and τ, (Rasmussen 2001).

Figure 2 shows in principle creep as a function of time for a material with a constant load that is subsequently removed.

The measured creep that develops in the mass exposed to constant stress, as a function of time is adjusted the Clouser equation. Adjusting the creep data to the Clouser equation it is found that the equation can be linear by logarithm in the following way:

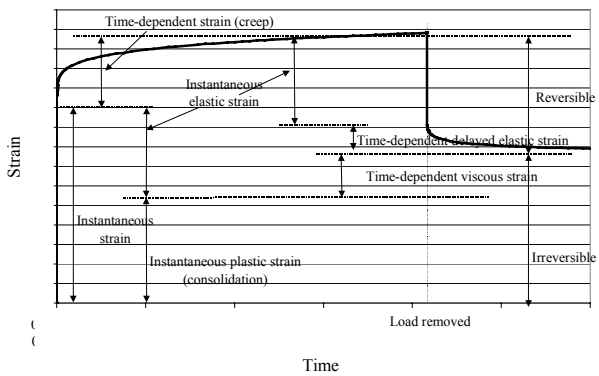

Figure 2 Typical example of creep as a function of time for a material with a constant load that is subsequently removed.

$$Y = Y_0 + \alpha X$$

where

$$Y = \log_{10}\left(Ec(t) - 1\right)$$

$$X = \log_{10} t$$

$$Y_0 = -a_1 \log_{10} \tau$$

$$\alpha = a_1$$

Here X_0 is found by using:

Y=0 which gives:

$$X_0 = -\frac{Y_0}{\alpha}$$

and a_1 and τ can be determined as:

$$a_1 = \alpha = -\frac{Y_0}{X_0}$$

$$\tau = 10^{-Y_0/\alpha} = 10^{X_0}$$

An extract of the measured creep data, for at least 3 load levels, is adjusted to the linear logarithm creep equation by the least square method.

The elastic module used is the average instantaneous elastic modulus found from unloading. It should be noted that the elastic modulus found from the lighter loads could be defective because of the displacement transducer used and because of the low unloading ratio of the total load.

6.7 Determining of creep parameters

From the experiments the travel of the disc placed on top of the loose-fill material as a function of time is recorded. The travel of the disc is denoted u and the start position of the disc is set to zero. The height of the loose-fill material is denoted h_0 and the time, t is set to zero at test start. At the time, t_1 the added load is carefully removed. The load mounted on top of the disc at test start is denoted L_0 (kg) and the relieved load at $t = t_1$ is denoted L_1 (kg).

From this input the creep parameters are found using the following steps.

1) Test data are shown in a diagram presenting strain as a function of time. In the diagram stress and the time of load relieve is noted.

   Strain is given as $\varepsilon = \frac{u}{h_0}$

   loaded stress is $\sigma_0 = \frac{L_0 g}{A}$

   relieved load is $\sigma_1 = \frac{L_1 g}{A}$, where the internal horizontal area of the cylinder is denoted A (m^2) and g = 9.81 m/s^2 is the gravitational acceleration.

2) Determine the Elastic module from the load relieve at the highest load level.

   $E = \frac{\sigma_1}{\left(\varepsilon_{1,0} - \varepsilon_{1,1}\right)}$, where $\varepsilon_{1,0}$ is the strain just before the load relieve and $\varepsilon_{1,1}$ is the strain after the load relieve.

3) Determine the instantaneous elastic strain given by $\varepsilon_{0,E} = \frac{\sigma_0}{E}$

4) Measure the instantaneous strain, $\varepsilon_{0,m}$ from loading, diagram given in 1).

5) Determine the consolidation given by $\varepsilon_c = \varepsilon_{0,m} - \varepsilon_{0,E}$

6) Determine $C(t) - C_1$ where $C(t) = \frac{\varepsilon}{\sigma_0}$ and

$$C_1 = \frac{\varepsilon_c}{\sigma_0}$$

7) Determine $X = \log_{10}(t)$ and $Y = \log_{10}(E(c(t)-C_1)-1)$.
8) X and Y are shown in a logarithm diagram for i.e. $-1 < X < \log_{10}(t_1)$.
9) A linear model $Y=Y_0+\alpha X$ is adjusted to the X, Y data by the least square method. The linear logarithm is shown including the used part of the test data together with the equation for the linear logarithm.
10) Determine a_1 and τ from $a_1 = \alpha$ and $\tau = 10^{-Y_0/\alpha}$
11) Determine and show in diagram under 1), $(c(t)+C_1)\sigma_0$ for $t< t_1$ and $(c(t)+C_1)\sigma_0 - (c(t-t_1))\sigma_1$ for $t \geq t_1$.
12) Adjust the instantaneous strain, $\varepsilon_{o,m}$, and the used part of the X, Y test data by interaction to achieve a good agreement between the modelled creep (shown in 11)) and test data (shown in 1)).

6.8 Expression of results

The results of the test are given as measured strain time curves shown together with the adjusted Clouser equation clearly marked with the individual load level, temperature and relative humidity used.

In addition a figure showing the linear logarithm X and Y are shown including the used part of the test data together with the adjusted linear logarithm.

Calculated values as the instantaneous elastic modulus, the relaxation time, and the creep exponent and instantaneous strain according to load level is registered together with the tested density of the loose-fill material.

Furthermore 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.

6.9 Accuracy

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

6.10 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 samples for every noted load level specified by test equipment load and flexible load
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 6.7
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.

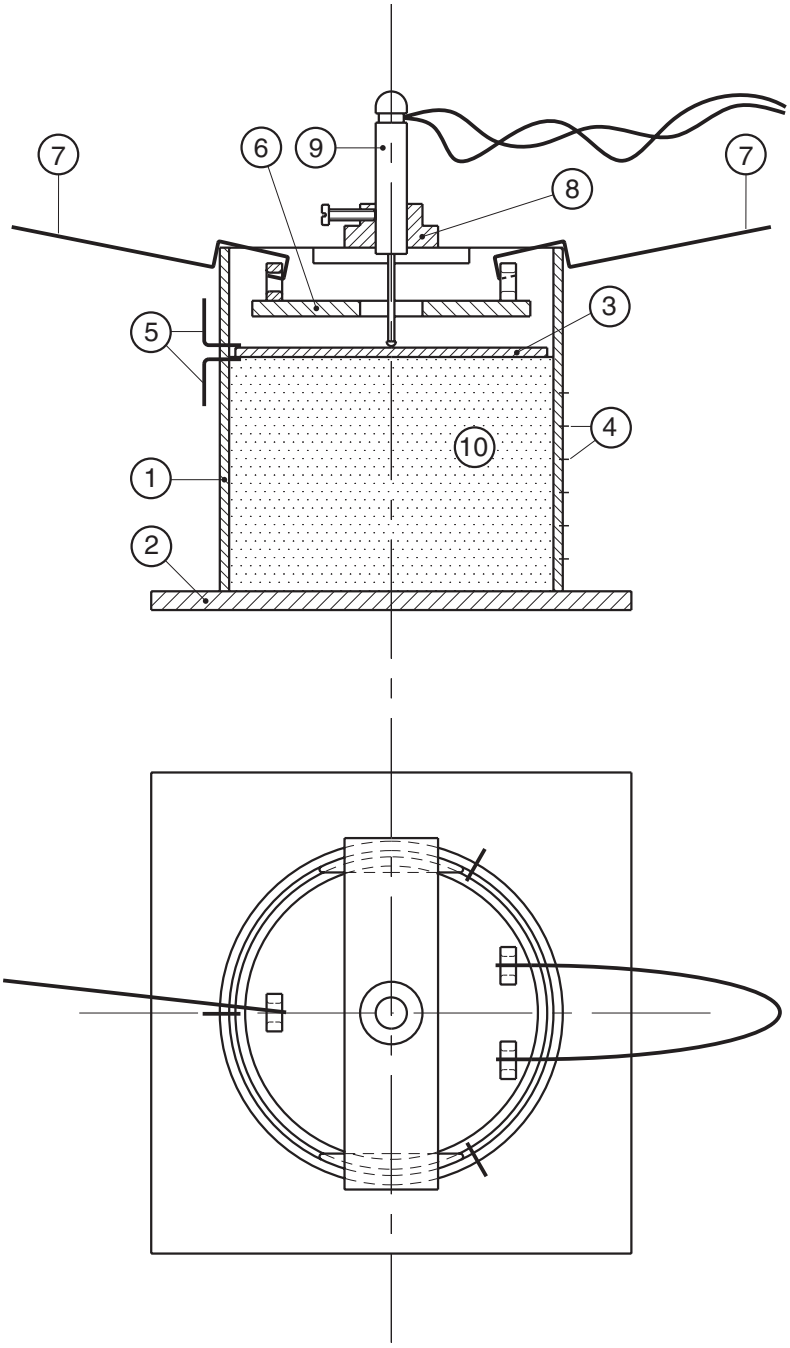

Figure 1 Apparatus to measure instantaneous strain and creep for loose-fill material. Top: vertical section. Bottom: plan. 1: 104.5 mm Ø; acrylic cylinder of 110 mm height. 2: 5.5 mm thick acrylic plate. 3: 3 mm thick acrylic disc. 4: 10 mm marks. 5: sticks. 6: load disc. 7: load and off-load hangers. 8: bridge. 9: LVDT displacement transducer. 10: loose-fill material.

Appendix B

Strain-time diagram for CFI

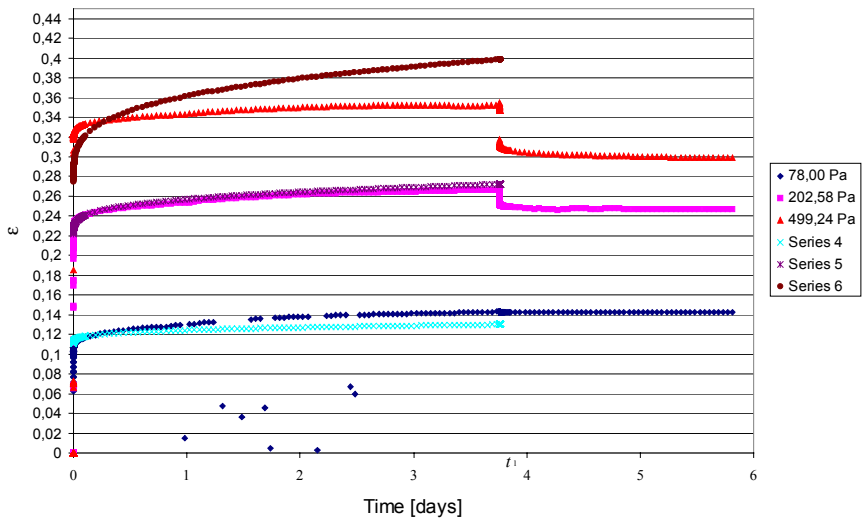

Figure 5. Strain-time diagram for CFI with a density of 30 kg/m^3 at 23 °C and 50 % RH. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

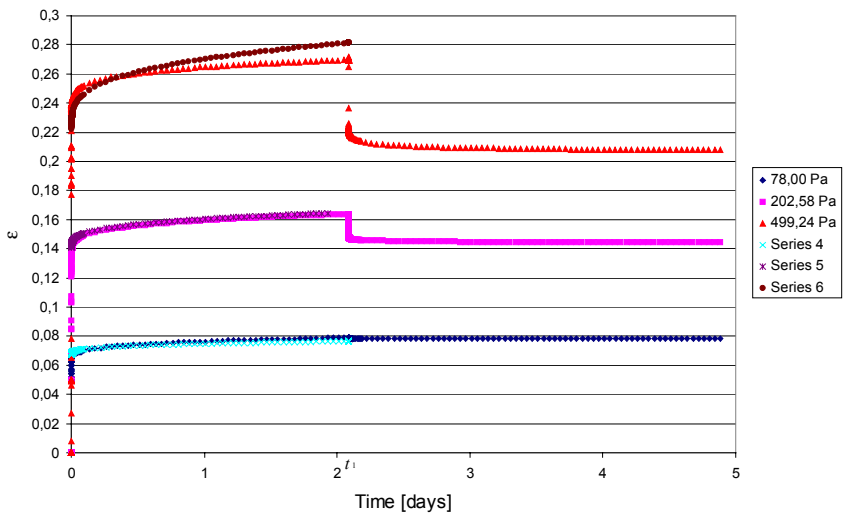

Figure 6. Strain-time diagram for CFI with a density of 42 kg/m^3 at 23 °C and 50 % RH. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

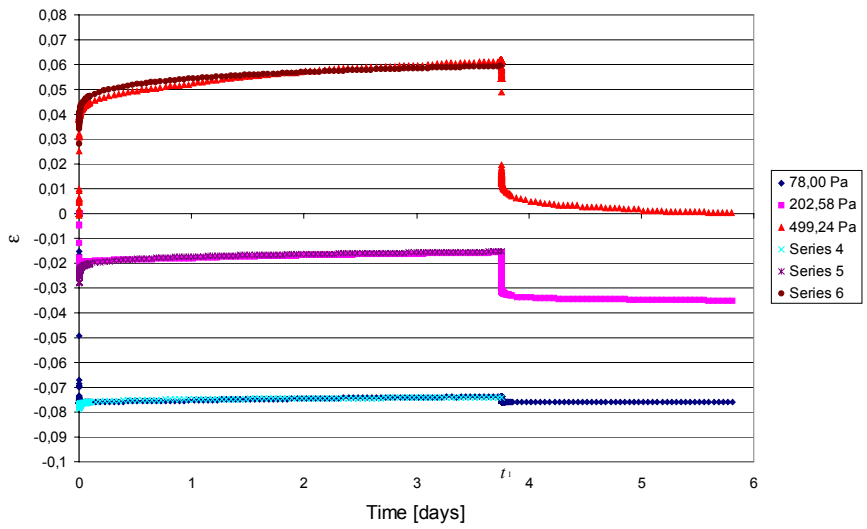

Figure 7. Strain-time diagram for CFI with a density of 60 kg/m^3 at 23 °C and 50 % RH. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

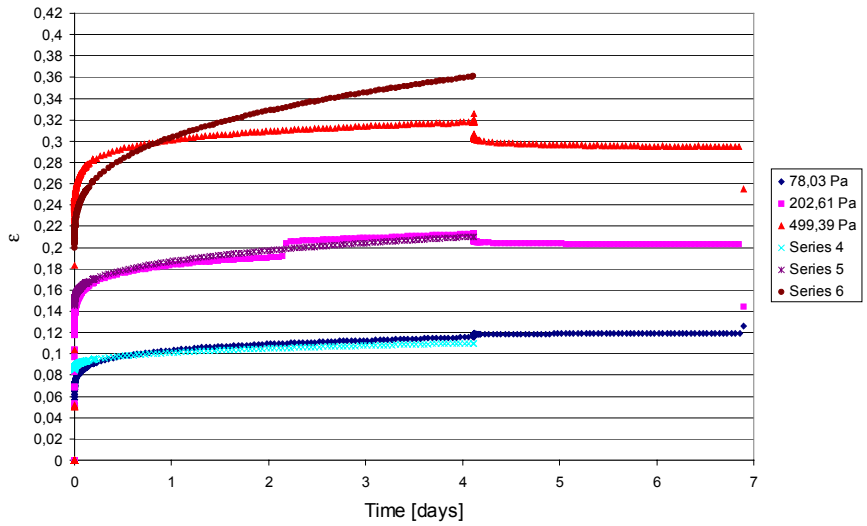

Figure 8. Strain-time diagram for CFI with a density of 42 kg/m^3 at 23 °C and 80 % RH. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

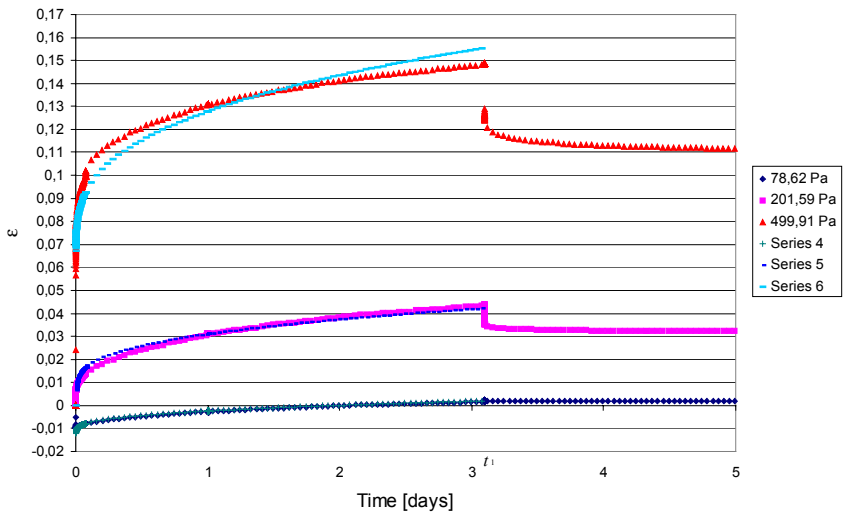

Figure 9. Strain-time diagram for CFI with a density of 50 kg/m^3 at 23 °C and 80 % RH. CFI was exposed to a constant load until the time denoted t_1 and subsequently partly relieved of its load. The Clouser equation for the stress levels starting at 78, 202 and 499 Pa is denoted series 4, series 5 and series 6, respectively.

Appendix C

SP report

RAPPORT

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Datum / *Date*	Beteckning / *Reference*	Sida / *Page*
2001-09-24	ETleb 60031	1 (7)

Samkalibrering av provmetod för lösfyllnadsisolering

(2 bilagor)

Uppdrag/ bakgrund

SP har av BY og BYG fått i uppdrag att framställa en provutrustning enligt beskrivning av en provmetod samt utföra försök med denna. By og BYG har utvecklat provmetoden som återfinns i skriften *NORDTESTMETODE: Loose-fill insulation in walls – test and modelling of creep,* daterat 2001-02-02, där en undersökning av By og BYG ligger till grund för metoden. NORDTEST har beviljat ekonomiska medel till en utveckling av metoden samt samkalibrering av mätning av krypning för lösfyllnadsisolering.

Försöken har utförts av Lars Olsson SP 5/6-18/6, 23/7-10/9 2001 och av Lars Tobin SP 29/6-18/7 2001.

Mätdata/ mätresultat

De relevantaste mätningarna redovisas i diagram, se bilaga 2. Tabeller av mätdata och de övriga mätningarna redovisas per elekktroniskt dokument efter förfrågan.

Utrustning

För mätregistrering har en mätklocka används av märket Mitutoyo Digimatic Indicator, type IDF-150(mätintervall 0,001-50 mm) med Mitutoyo Digimatic Multiplexer MUX-10. För uppvägning av material har en våg av märket Mettler PC 16 (mätnoggrannhet 0,1 gram) använts. Utrustning är kalibrerad enligt SWEDAC.

SPs försöksuppställning var placerad i ett klimatrum (23 ^{0}C,+/- 2 ^{0}C, och 50% RF, +/- 5 %) med ett bjälklag av betong och uppställd på en cellplastskiva med 150 mm underliggande mineralullsisolering som hämmar vibrationer, se bild 2.

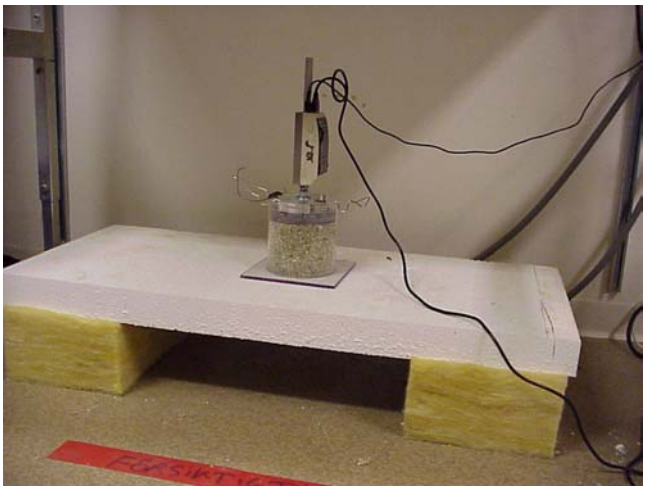
För att lösgöra materialet användes ett mekaniskt verktyg (stor visp), se bild 3. Vid ett tillfälle användes tryckluft.

Ackrediterat laboratorium utses av Styrelsen för ackreditering och teknisk kontroll (SWEDAC) enligt lag. Verksamheten vid de svenska ackrediterade laboratorierna uppfyller kraven enligt SS-EN 45001 (1989), SS-EN 45002 (1989) och ISO/IEC Guide 25 (1990:E). Denna rapport får endast återges i sin helhet, om inte SWEDAC och SP i förväg skriftligen godkänt annat.

Accredited laboratories are appointed by the Swedish Board for Accreditation and Conformity Assessment (SWEDAC) under the terms of the Act. The Swedish accredited laboratories meet the requirements set up in SS-EN 45001 (1989), SS-EN 45002 (1989) and ISO/IEC Guide 25 (1990:E). This report may not be reproduced other than in full, except with the prior written approval of SWEDAC and SP.

Den av SP tillverkad provutrustningen kan ses på bild 1.

1. Foto av provutrustning



2. Foto av provutrustning och vibrationshämmande uppställning av mineralullsskivor i klimatrum.

3. Foto av visp

Konditionering

Konditionering (23 ^{0}C,+/- 2 ^{0}C, och 50% RF, +/- 5 %) av BY og BYGs material startade i mitten av mars 2001 och konditionering av ersättningsmaterial, Ekofiber vägg 010313 SP 15 41 03, startade 23 maj 2001.

Förmodligen fanns det skillnader mellan materialen, EKOFIBER från Danmark tillsänt av BY og BYG och Ekofiber vägg 010313, SP 15 41 03 från Sverige, då det utseendemässigt upplevdes skillnader i materialstrukturen.

Provcylindern och dess tillbehör har tvättats med ljummet såpavatten och sköljts med destillerat vatten. Därefter har den avtorkats med papper och lufttorkats.

Försök

Det första fullbordade försöket startade 5 juni. Vid bearbetning av resultaten uppdagades bl a att materialet expanderade utanför mätområdet som det var avsett för, varvid deformationen slutade på ett konstant värde. Orsaken var att mätklockans ändintervall placerades förnära nollnivån ,mätintervallet blev begränsat uppåt. Detta eftersom vi inte förväntade oss en kraftig expansion. Detta resulterade i att ett antal försök (försök 1-13) måste kasseras.

Därefter har By og BYG fått ta del av ett antal försök under perioden mellan försök 14-22 som inte uppvisade samma resultat som framkommit i BY og BYGs försök.

I mitten av augusti, 14/8, gjorde BY og BYG företaget en precisering av hur starten av försöken skulle utföras. Denna precisering avvek från beskrivningen i provmetoden (daterat 2001-02-02) i punkt 6.4. Den nya metoden har använts för försöken 23-34.

Diagrammen i bilaga 1 (försök 23-33) visar att den momentana krypningen vid starten av SPs försök inte stämmer överens med resultaten från BY og BYGs försök. Den tidsavhängiga krypningen och den momentana krypningen vid avlastning stämmer dock med resultaten från BY og BYG.

I mitten av juli tog det material som tillsänts av BY og BYG slut. I stället användes, efter samråd med BY og BYG, ett Svenskt material av Ekofiber vägg 010313, SP 154103. Detta Svenska material användes för försöken 11-28 och 32-33, dock inte för försöken 29-31 då vi återanvände BY og BYGs material för en jämförande studie. Denna jämförelse uppvisade inga direkta skillnader.

Förbearbetning av material innan montering

Metoden föreskriver användning av tryckluft. För försök 1-30 och 32-33 har SP använt en mekanisk metod till att lösgöra materialet/lösullen. För försök 31 har tryckluft används. Om resultaten jämförs mellan 30 och 31 som är utfört med olika förbearbeting ,enligt ovan, erhålls dock likartat resultat. Det tyder på att förbearbetningen inte är en avgörande faktor för att förklara de uppkomna skillnader i resultat mellan SPs och By og BYGs försök.

Montering av materialet i provcylindern

SP har använt följande metod:
Strax innan montering av materialet i provcylindern har materialet lösgjorts (förbearbetatats) med hjälp av en roterande visp.

Materialmonteringen har delats upp i sju delar och efter varje delmontering har föreskrivet packningsverktyg använts för att trycka samman materialet, dock aldrig under varje delnivåmarkering. Därefter har de tre undre låssprintarna monterats i cylindern, skivan placerats på låssprintarna varefter de tre övre låssprintarna monterats.

Det finns inte beskrivet om provcylindern skall stå med lösull/provmaterial i provcylindern en tid innan försöket startas. SPs resultat tyder på att det fanns spänningar i materialet som medför att lösullen expanderar kraftigt då den låsta skivan lossats.

Start av mätning och registrering av mätdata

I försök 1-5 och 13-22 användes följande metod:

Detta utförande enligt metodbeskrivning (vår tolkning).

Innan montering av mätklocka och dess stativ hängdes belastningsskivan upp med hjälp av föreskrivna hållare på provcylinderns kant. Innan start nollställdes mätklockan på nollnivån, skivan var placerad på 70 mm över bottenplattan, där skivan var fixerad av sex lässsprintar.

Därefter startades mätningen. Efter att de sex låssprintarna lossats (vid detta tillfälle expanderade alltid materialet innan påverkan av last) sänktes belastingsskivan ner på skivan. Försöken pågick alltid minst 2 dygn. Efter detta avlastades skivan under minst 2 timmar som var avslutningen på försöken. Se nedan.

Förfarande i kronologisk ordning
1. Mätningen startades,
2. bortmontering av de sex låssprintarna,
3. nedsänkning av belastningsskivan,
4. efter minst två dygn avlastades skivan,
5. efter minst två timmar avslutades försöken.

I försök 6 –12 användes följande metod:

Detta utförande avvek från tidigare utförande (ny person - annan tolkning)

Innan montering av mätklocka och dess stativ hängdes belastningsskivan upp med hjälp av föreskrivna hållare på provcylinderns kant. Innan start nollställdes mätklockan på nollnivån, skivan var placerad på 70 mm över bottenplattan, där skivan är fixerad av sex lässsprintar.

Därefter startades mätningen. Efter att belastingsskivan sänkts ner på de tre övre låssprintarna lossades samtlig låssprintar. Försöken pågick alltid minst 2 dygn. Efter detta avlastades skivan under minst 2 timmar som var avslutningen på försöken. Se nedan.

Förfarande i kronologisk ordning

1. Mätningen startades,
2. nedsänkning av belastningsskivan på de tre övre sprintarna,
3. bortmontering av de sex låssprintarna,
4. efter minst två dygn avlastades skivan,
5. efter minst två timmar avslutades försöken.

Från försök 23 användes följande metod:

Detta försök gjordes efter precisering av By og BYG inför det 23 försöket.

Innan montering av mätklocka och dess stativ hängdes belastningsskivan upp på cylinderns kant. Innan start nollställdes mätklockan på nivån, skivan var placerad 70 mm över bottenplattan, där skivan var fixerad av sex låssprintar.

Därefter startades mätningen. Efter att de tre undre lässspintarna lossats (vid detta tillfälle sjönk aldrig skivan) sänktes belastingsskivan ner på skivan (belastningsskivan passerad fritt förbi de tre övre låssprintarna och placerades på skivan. Därefter lossades försiktigt de tre övre låssprintarna. Försöken pågick minst 2 dygn. Efter detta avlastades skivan (om den var belastad av belastningsskivan) under minst 2 timmar som avslutade varje försök. Se nedan.

Förfarande i kronologisk ordning:

1. Mätningen startades,
2. eventuellt bortmontering av de tre under låssprintarna,
3. nedsänkning av belastningsskivan på skivan (belastningsskivan passerar fritt förbi de tre övre sprintarna),
4. bortmontering av de tre övre låssprintarna,
5. efter minst två dygn avlastades skivan,
6. efter minst två timmar avslutades försöken.

Kommentarer till metodbeskrivning

Vid första genomgången av texten i provmetoden uppmärksammades att följande beskrivning kunde förtydligas i pkt 6.2: The plate is approximately 5.5 mm thick, and the cylinder and the disc are both approximately 3 mm thick.

The plate ändras till <u>The bottom plate</u>

Det uppstår förmodligen spänningar i materialet vid montering. Därför kan tiden mellan lösgörning/förbearbetning av provmaterial och montering av material i provcylindern och tiden mellan då materialet har rätt densitet (fixerad skiva) och start av försök ha betydelse.

När materialet utsätts för tryckluft (torr luft) utsätts materialet för en torkningsprocess som kan ha inverkan på det konditionerade materialet. Om materialet konditioneras ytterligare en tid torde det finnas risk under tiden för egensättning.

Det bör framgå att belastningen sker då materialet har rätt densitet, vilket kräver att skivan är låst uppåt vid belastning.

Det bör framgå att packningsverktyget inte får orsaka att isoleringsytan understiger nivåmarkering under montering av material.

Det bör finnas en beskrivning av belastningsskivan t ex 3 mm tjock, ursparning i skivan för de tre övre sprintarna för att den skall kunna sänkas ner på skivan förbi låssprintarna, m m.

Det mätintervall (minst 12 mm) som anges i metodbeskrivningen har inte varit tillräcklig då SPs försök krävt större intervall.

Då låssprintarna lossas finns risk för vibrationer/rörelser på utrustningen som kan inverka på resultatet. Tydligare anvisningar måste ges hur detta moment genomförs.

Det krav som normalt ställs på klimatrum är +/- 5 % RF framförallt då laborationspersonal uppehåller sig i rummet under kortare perioder.

Beräkning

Då den momentana krypningen för SPs försök inte uppträder på ett teoretiskt förväntat sätt är det inte möjligt att utföra beräkningar av krypningsfunktionen.

Diskussion angående försöken

Utifrån diagrammen framgår det att förväntat resultat inte uppträder för SPs försök. Eftersom inte den förväntade momentana sammantryckningen sker i startskedet förmodas att materialet har en inre spänning. Denna inre spänning ligger förmodligen kvar en tid då en stabilisering inte fått ske. Detta har vi också sett i ett fristående försök genom att vänta med starten en tid efter att skivan är fixerad med rätt materialdensitet.

Då tryckluft används riskerar de lättare fibrerna att hamna överst vid lösgöring/förbearbetning av material och detta torde rimligen innebära att materialet fraktioneras. Detta innebär att man kan förvänta lokala variationer i materialet efter denna förbehandling.

KONKLUSION

SP har inte erhållit samma resultat utifrån teorin i beskrivningen i provmetoden. Det ser framförallt ut som att kompletteringar av metoden krävs för att säkra att det inte uppstår avvikelser i utförandet. De punkter som är problematiska är förbearbetning av material, montering av material, tiden mellan fixering av skivan och starten när pålastning och lossning av skivan utförs. Detta bör detaljeras och beskrivas utförligt i kronologisk ordning.

Vår bedömning är att den föreslagna metoden kräver stor noggrannhet vid utförande samt erfaren användare.

Den föreslagna metoden kan vara lämplig till jämförelse av produkter och värdering av deras egenskaper som det är beskrivet i By og BYGs rapport. Men det är tveksamt om den är användbar som generell provningsmetod utan flera samkalibreringar och en mera utförlig metodbeskrivning.

Det torde vara intressant att veta hur stora interna variationer det är i en produkt som Ekofiber eftersom det framställs av olika pappersmaterial och därför inte förväntas ha samma sammansättning. Erfarenhet visar att strukturen i materialet kan variera för samma tillverkare.

SP Sveriges Provnings- och Forskningsinstitut
Byggnadsfysik

Anker Nielsen
Tekniskt ansvarig

Lars Olsson
Teknisk handläggare

Genom
Lars Tobin
Sektionschef

Bilagor:

1. Mätprotokoll
2. Diagram, försök 17, 18,20, 23-33

RAPPORT

Handläggare, enhet / *Handled by, department*	Datum / *Date*	Beteckning / *Reference*	Sida / *Page*
Lars Olsson, Byggnadsfysik	2001-09-24	ETleb 60031	1 (1) Bilaga 1

Mätprotokoll

Försök	Belastning (gram)	Densitet (kg/m^3)	Start datum	Stopp datum	Kommentar
1	175	50	5/6	8/6	Dålig på- och avlastning
2	175	50	11/6	13/6	Dålig avlastning
3	175	50	14/6	16/6	
4	175	50	16/6	18/6	
5	175	50	18/6	20/7	Bugg i mätprogram
6	175	50	29/6	2/7	
7	175	50	2/7	6/7	
8	175	50	6/7	9/7	
9	175	60	9/7	13/7	
10	175	60	13/7	15/7	De första 5 sek ej med
11	175	60	15/7	18/7	Nytt material Ekofiber 010313,
12	436	50	18/7	23/7	Stativ ur läge
13	436	50	23/7	25/7	Fel på datalagring
14	436	50	25/7	27/7	
15	436	50	27/7	30/7	
16	436	60	30/7	1/8	Problem vid avlast. Vikterna tar för stor volym
17	436	60	1/8	3/8	
18	436	60	3/8	5/8	
19	175	42	6/8	8/8	
20	175	42	8/8	11/8	
21	436	42	11/8	13/8	
22	175	50	13/8	STOPP	
23	436	50	14/8	17/8	**NY METOD GÄLLER**
24	175	50	17/8	20/8	
25	175	42	20/8	22/8	
26	436	42	22/8	24/8	
27	436	60	24/8	27/8	
28	175	60	27/8	29/8	
29	175	50	29/8	31/8	Återanvändning av SBIs material
30	175	50	31/8	3/9	Återanvändning av SBIs material
31	175	50	3/9	6/9	Återanvändning av SBIs material, även förb. med tryckluft
32	69	42	6/9	8/9	Ekofiber 010313 gäller nedan
33	69	50	8/9	10/9	
34	69	60	10/9	13/9	lagringsfel

SP Sveriges Provnings- och Forskningsinstitut, Box 857, 501 15 BORÅS, Tfn 033-16 50 00, Fax 033-13 55 02, E-post info@sp.se, Org.nr 556464-6874
SP Swedish National Testing and Research Institute, Box 857, SE-501 15 BORÅS, SWEDEN, Telephone + 46 33 16 50 00, Telefax + 46 33 13 55 02, E-mail info@sp.se, Reg.No 556464-6874

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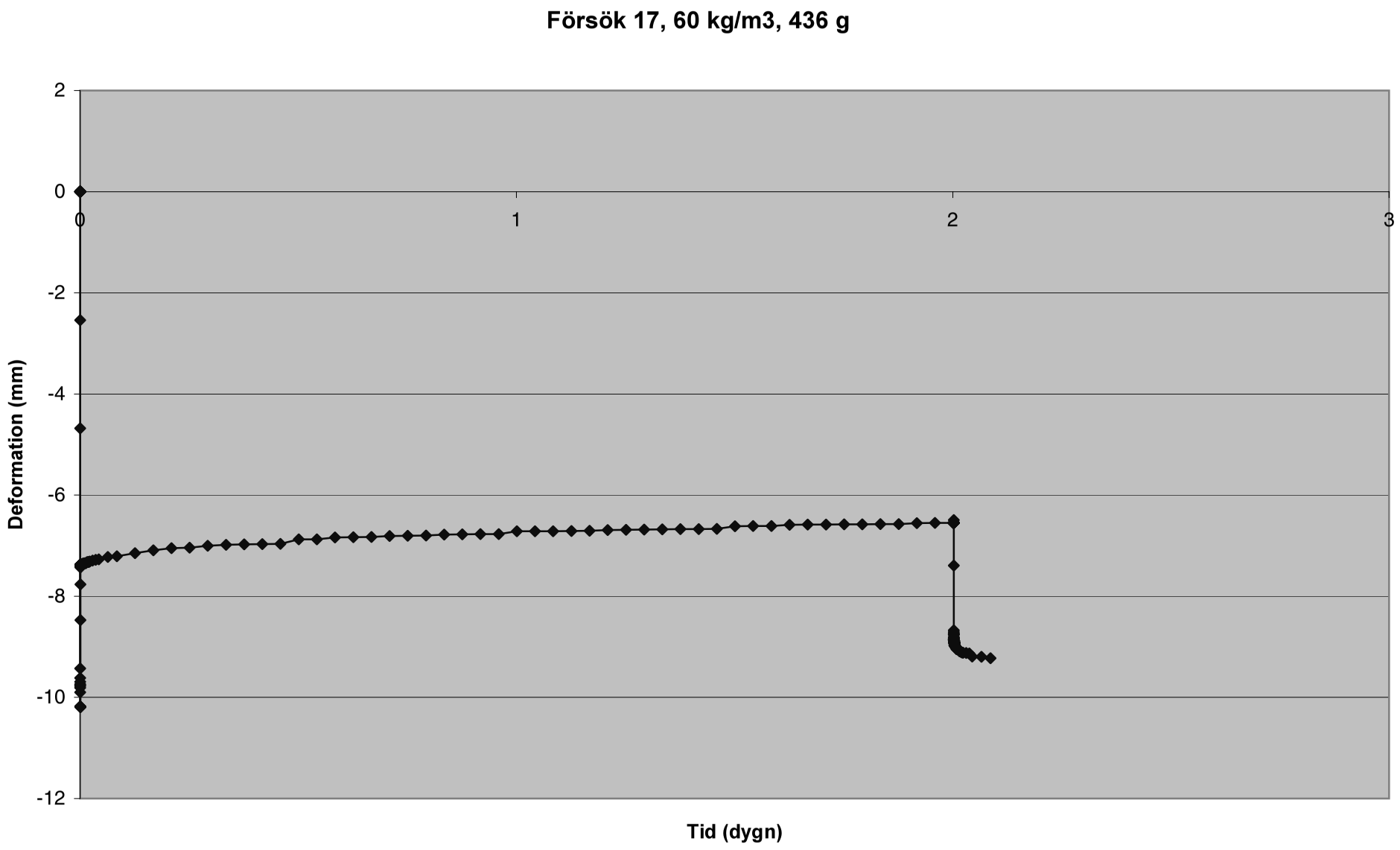
Försök 17, 60 kg/m3, 436 g
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-4
-6
-8
-10
-12
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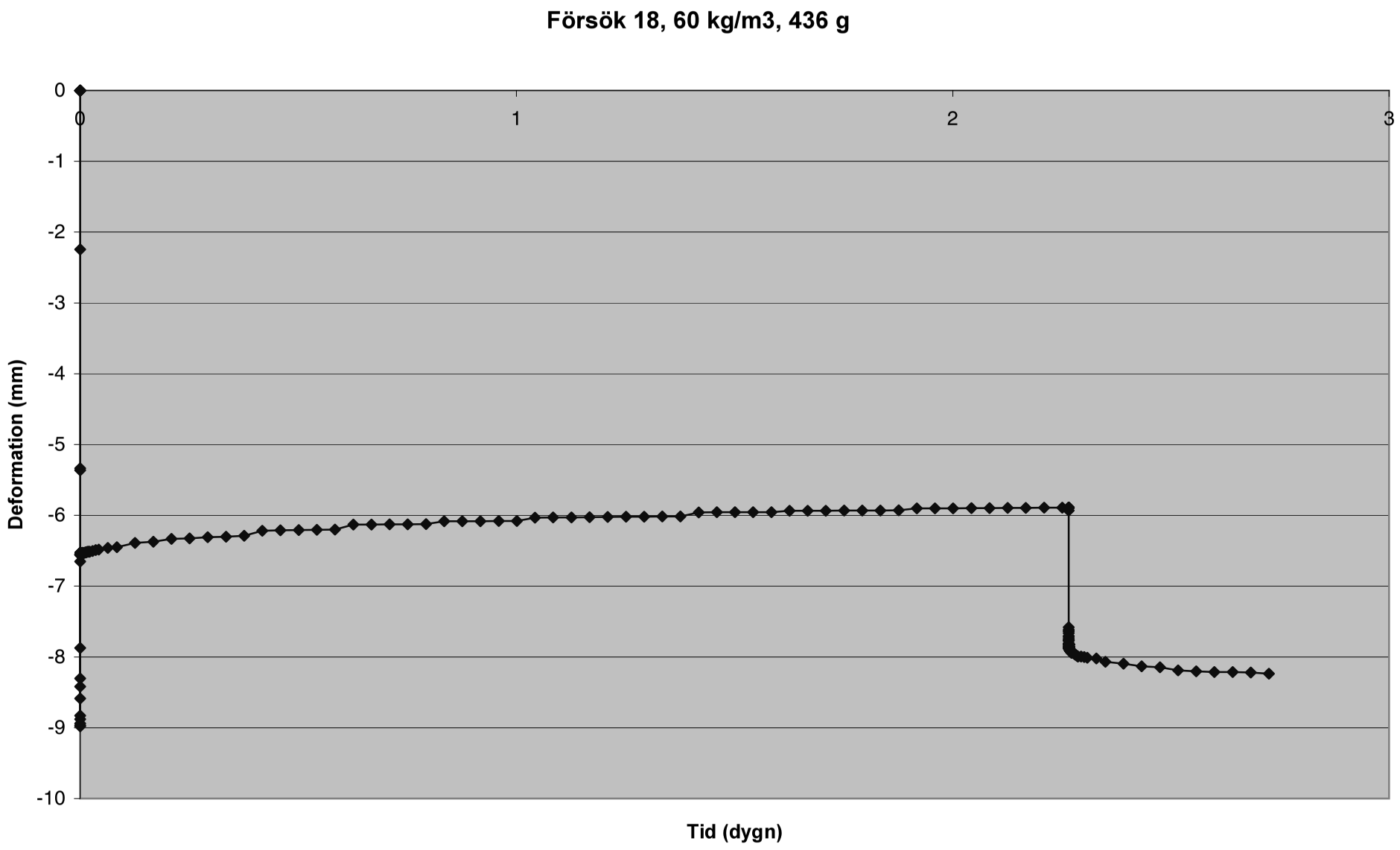
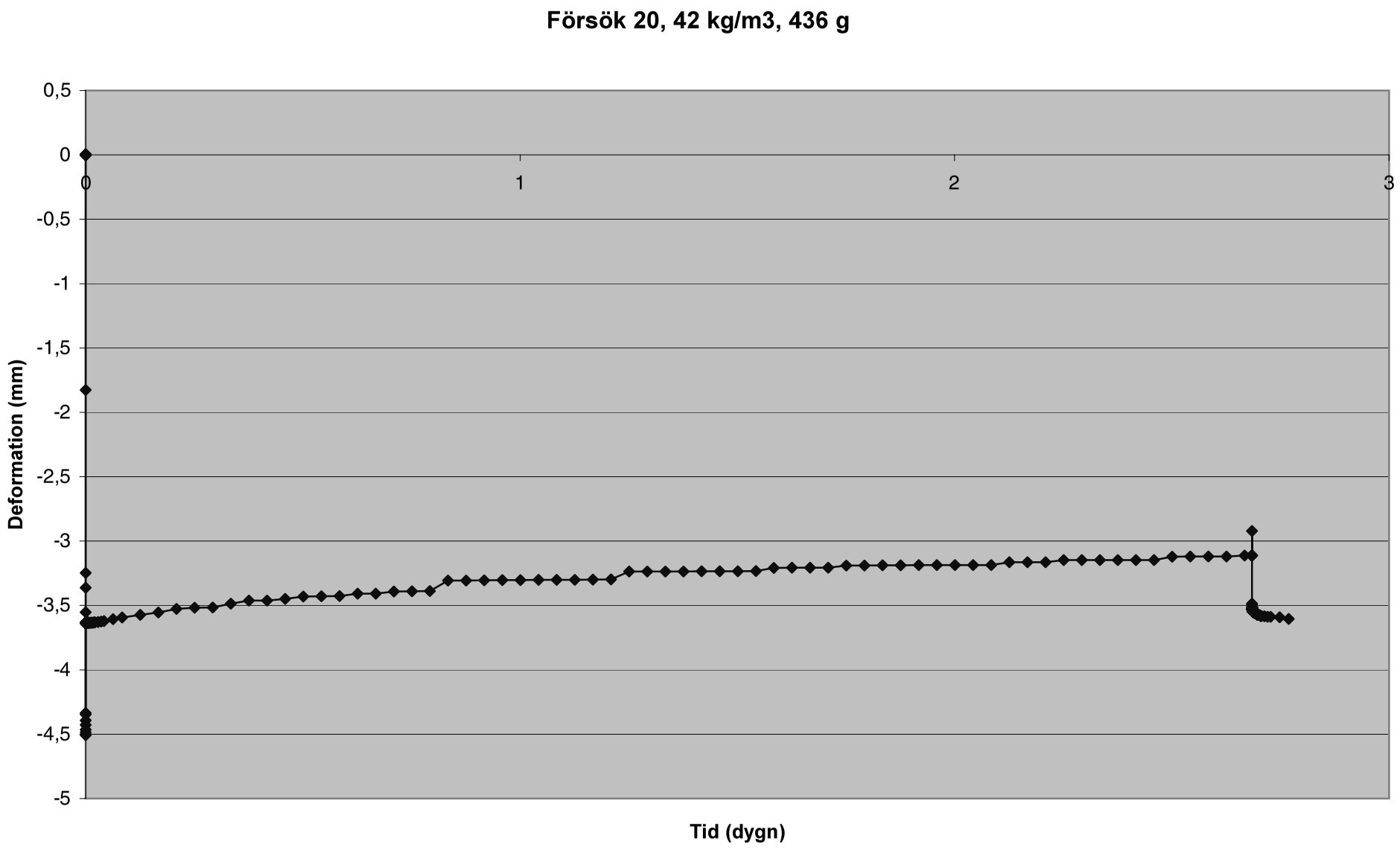
1
2
3
Deformation (mm)
Tid (dygn)


Försök 18, 60 kg/m3, 436 g
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 20, 42 kg/m3, 436 g
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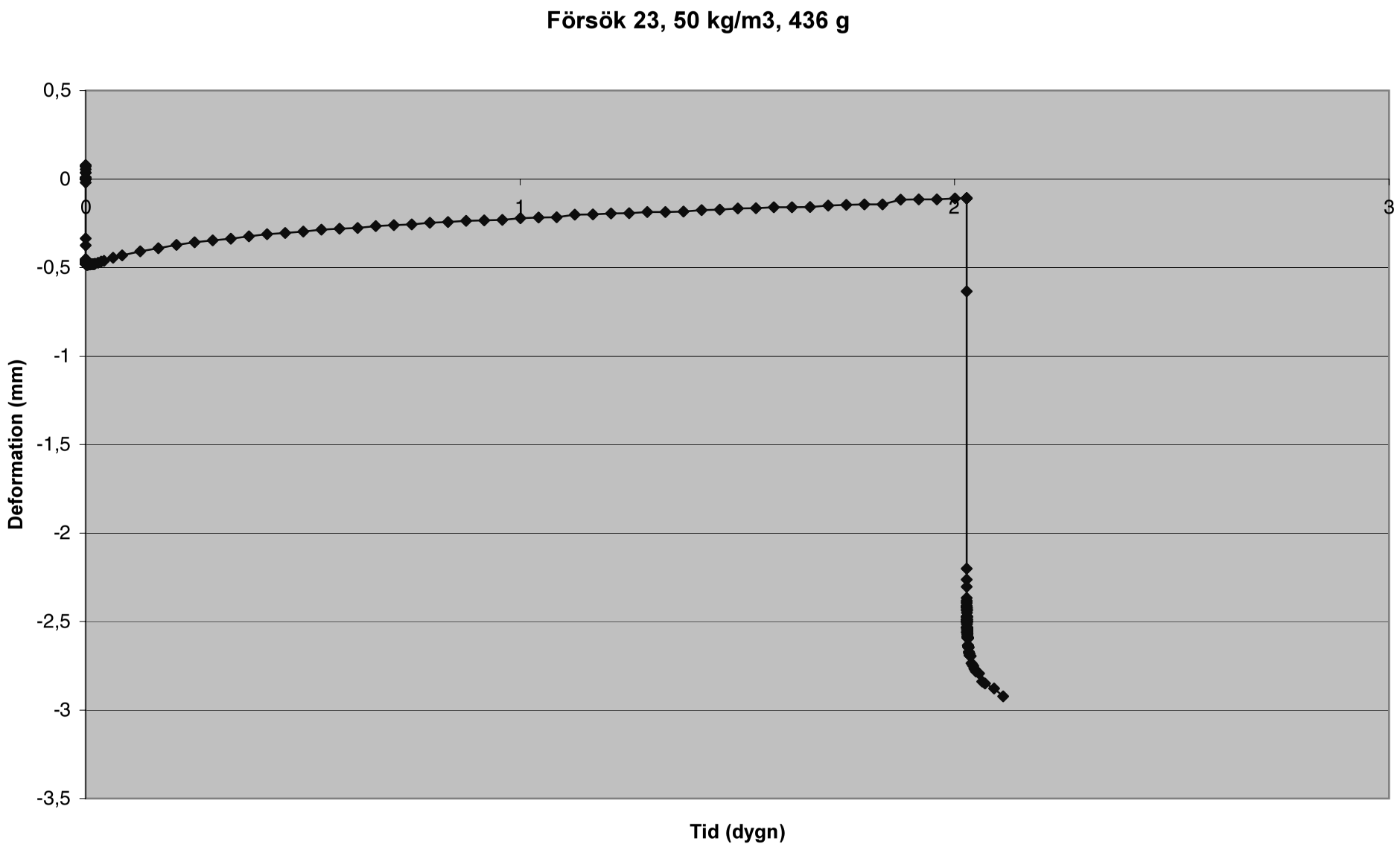
-1
-1,5
-2
-2,5
-3
-3,5
-4
-4,5
-5
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 23, 50 kg/m3, 436 g
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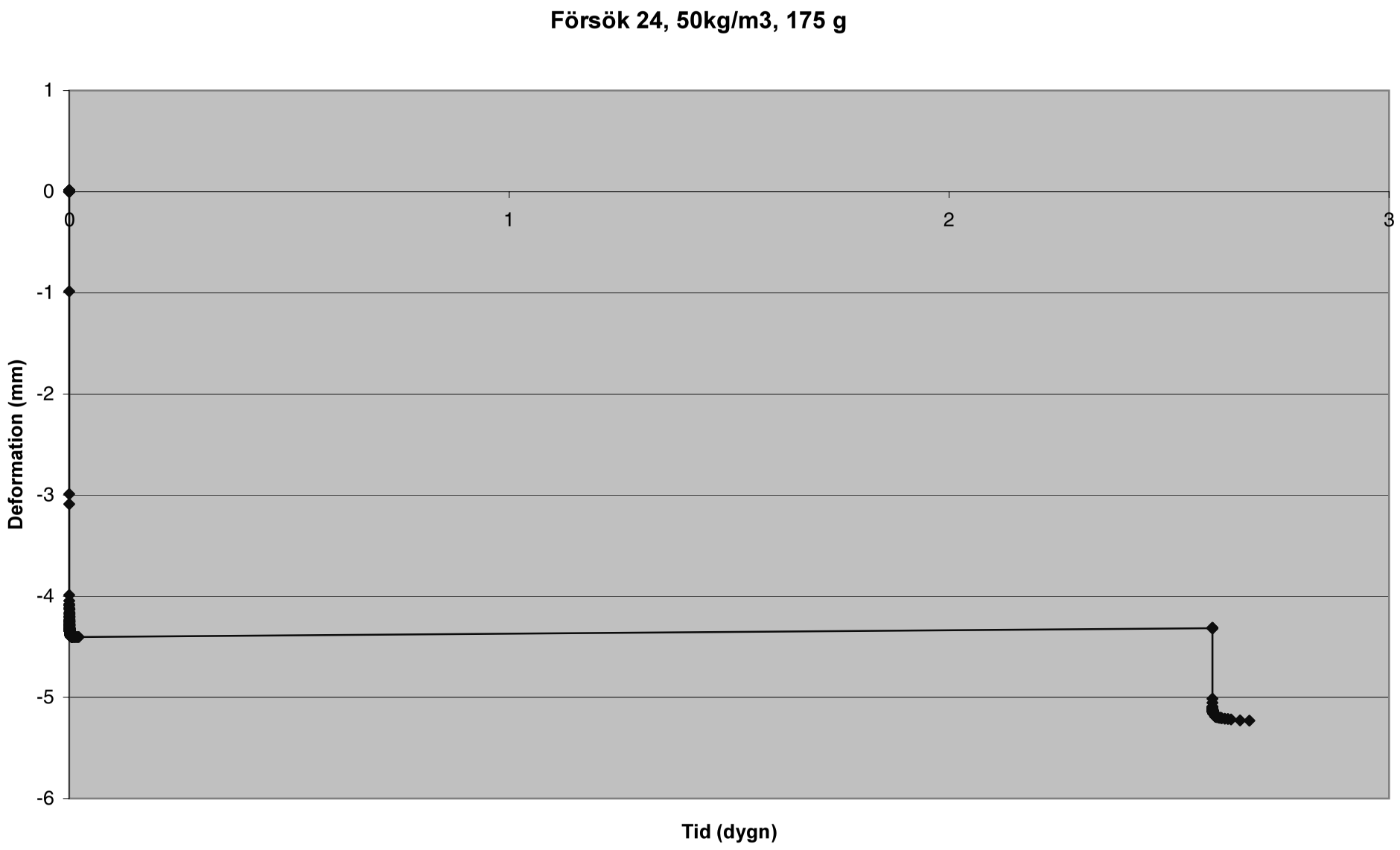
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 24, 50kg/m3, 175 g
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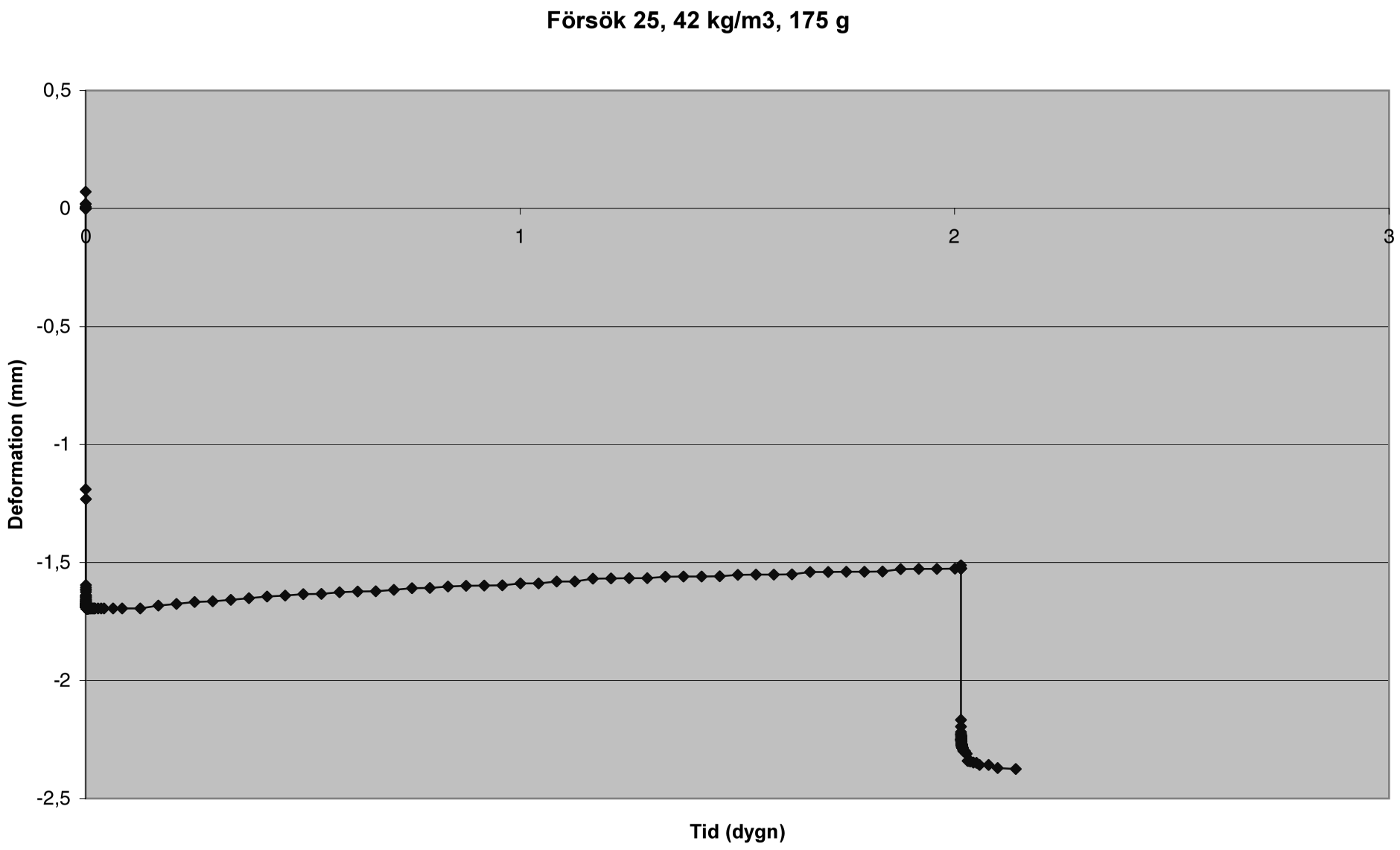
-1
-2
-3
-4
-5
-6
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 25, 42 kg/m3, 175 g
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-1
-1,5
-2
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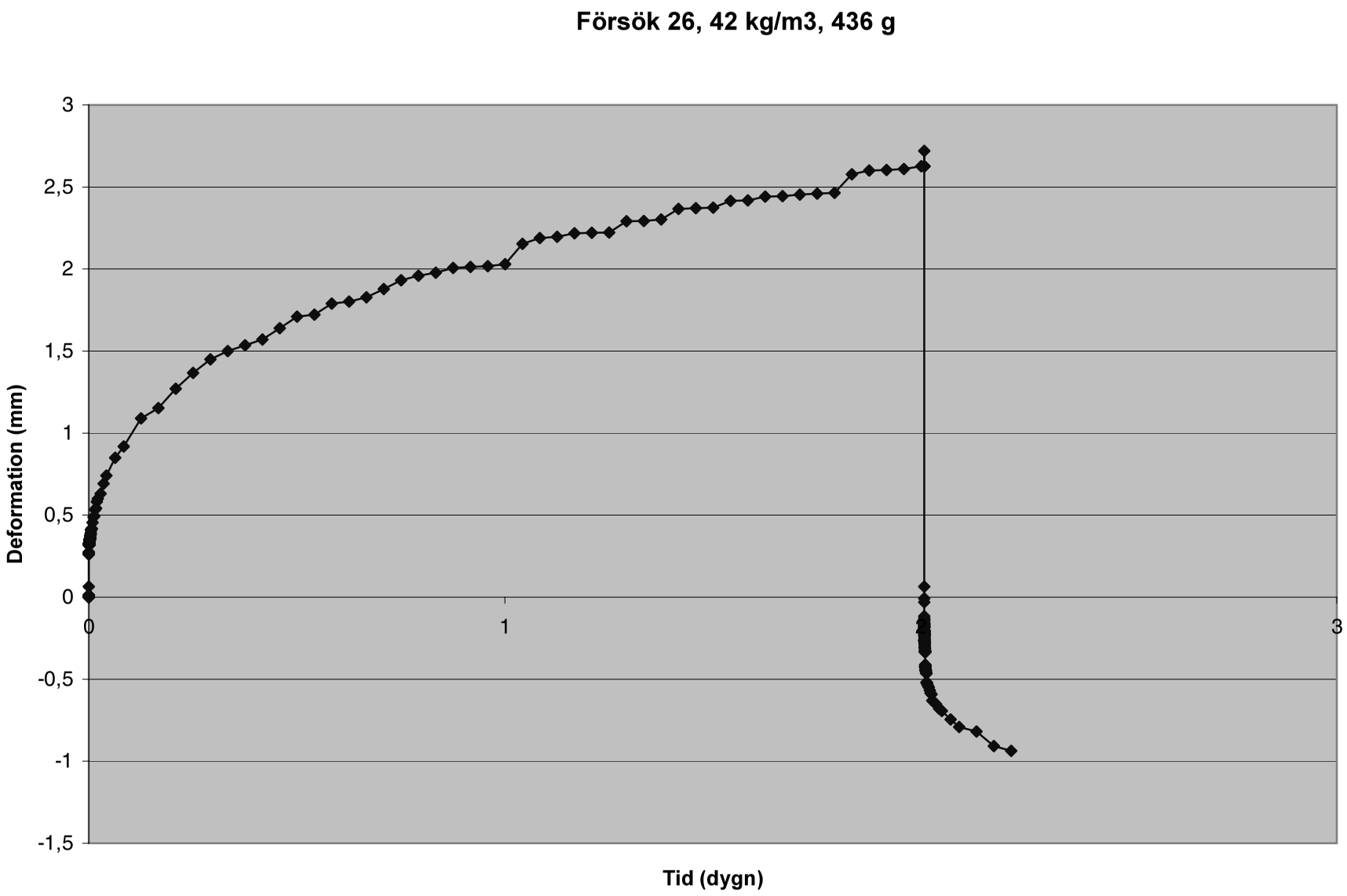
1
2
3
Deformation (mm)
Tid (dygn)


Försök 26, 42 kg/m3, 436 g
Deformation (mm)
Tid (dygn)
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2,5
2
1,5
1
0,5
0
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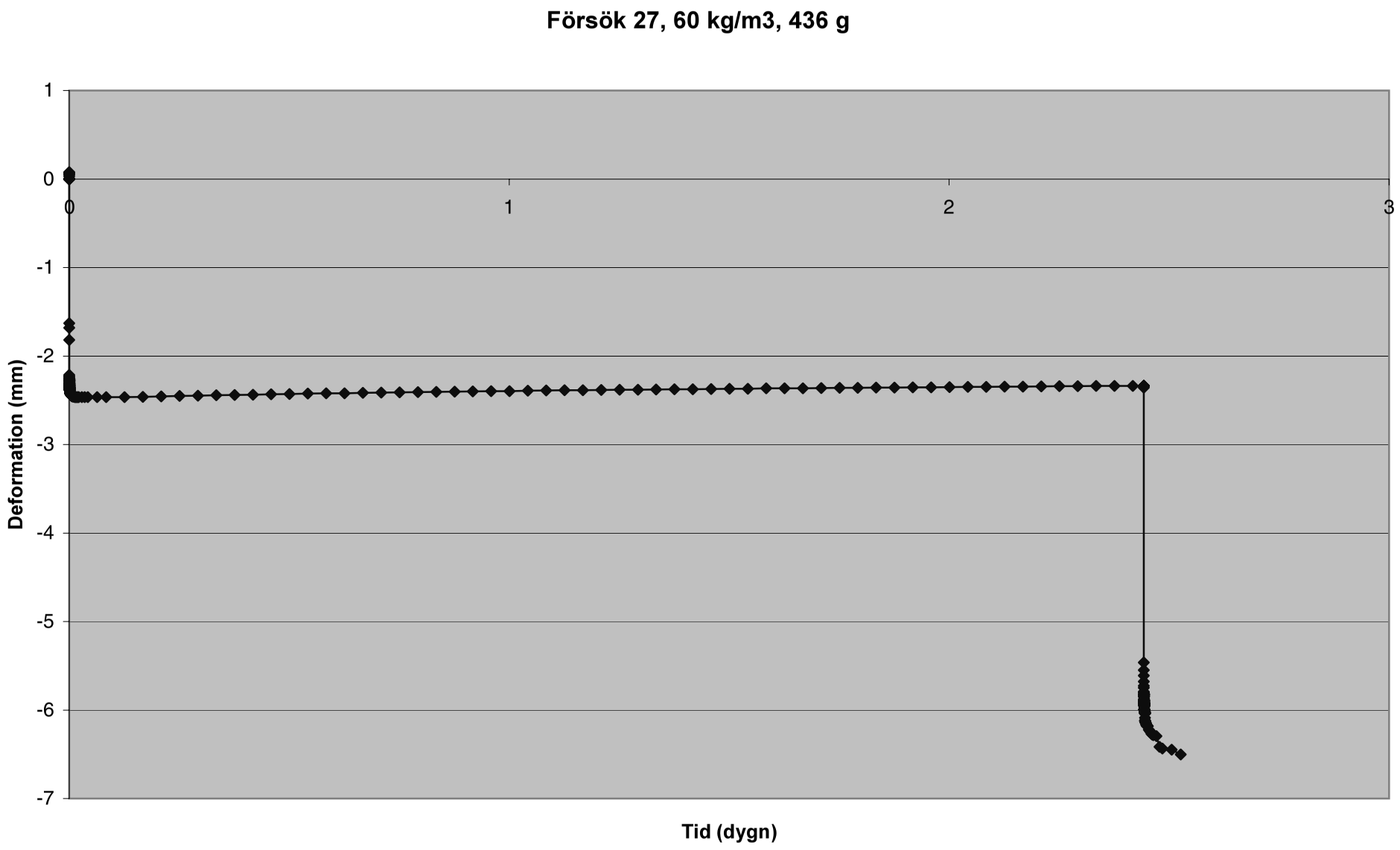
-1
-1,5
0
1
3


Försök 27, 60 kg/m3, 436 g
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0
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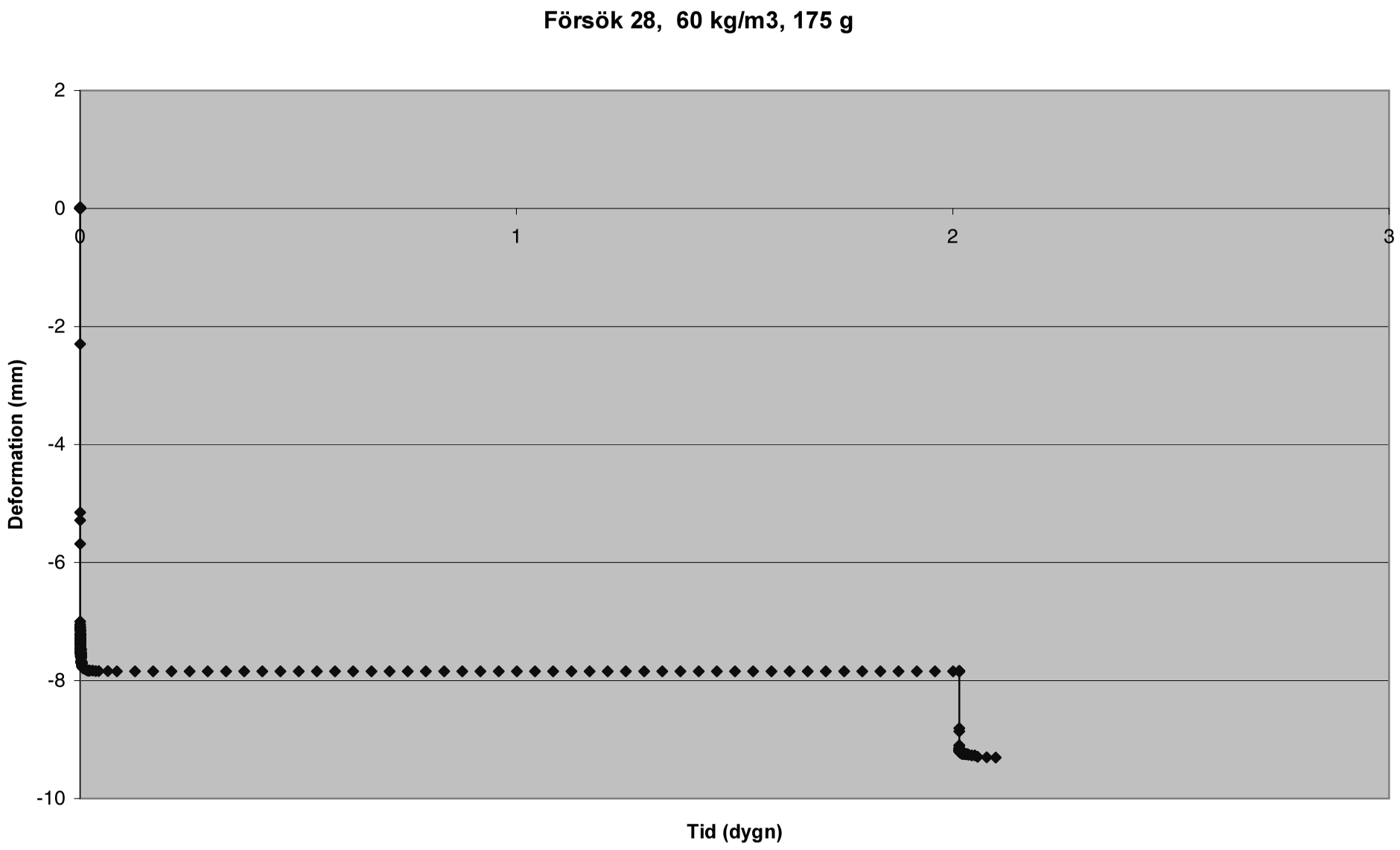
-2
-3
-4
-5
-6
-7
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 28, 60 kg/m3, 175 g
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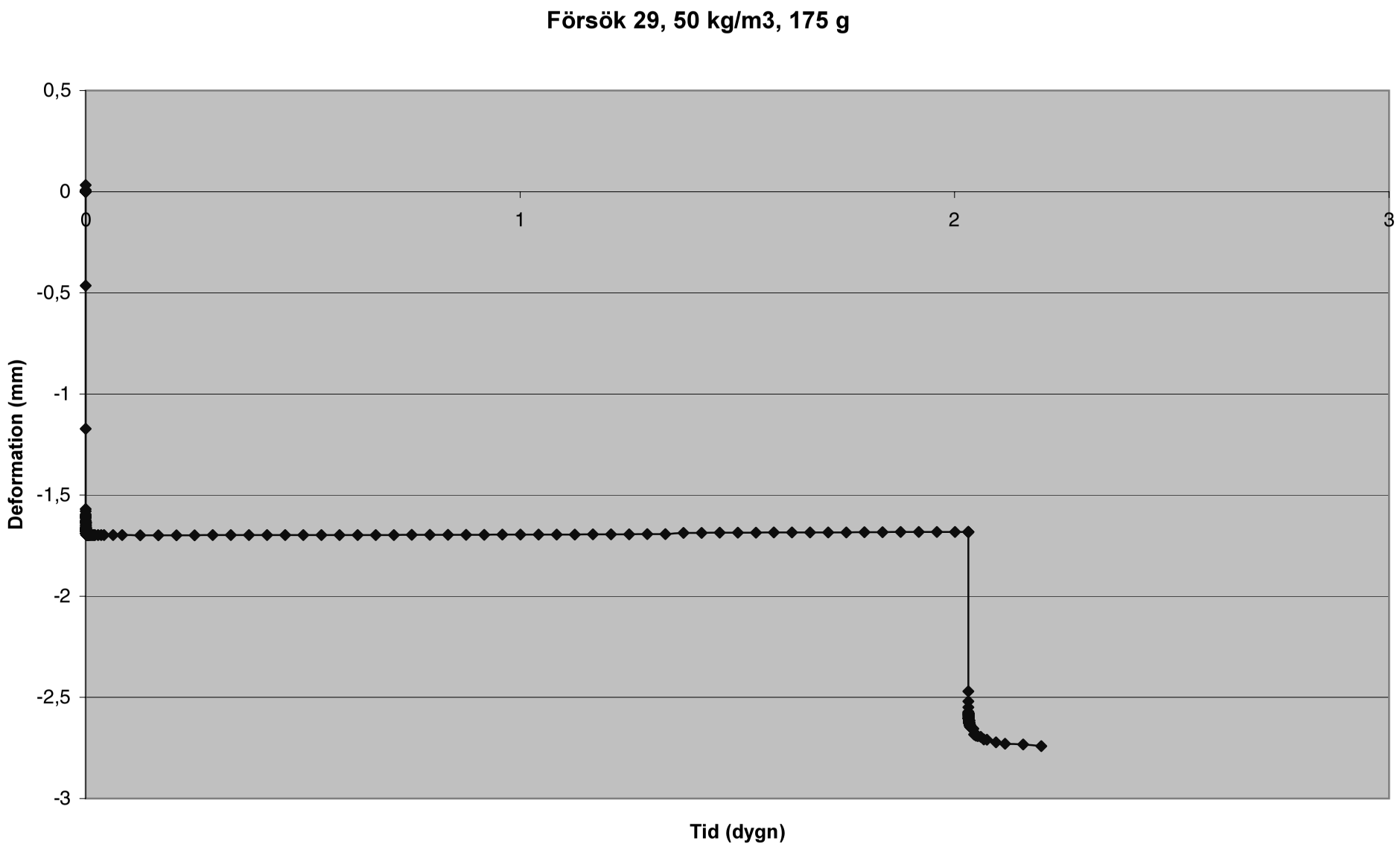
-2
-4
-6
-8
-10
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 29, 50 kg/m3, 175 g
0,5
0
-0,5
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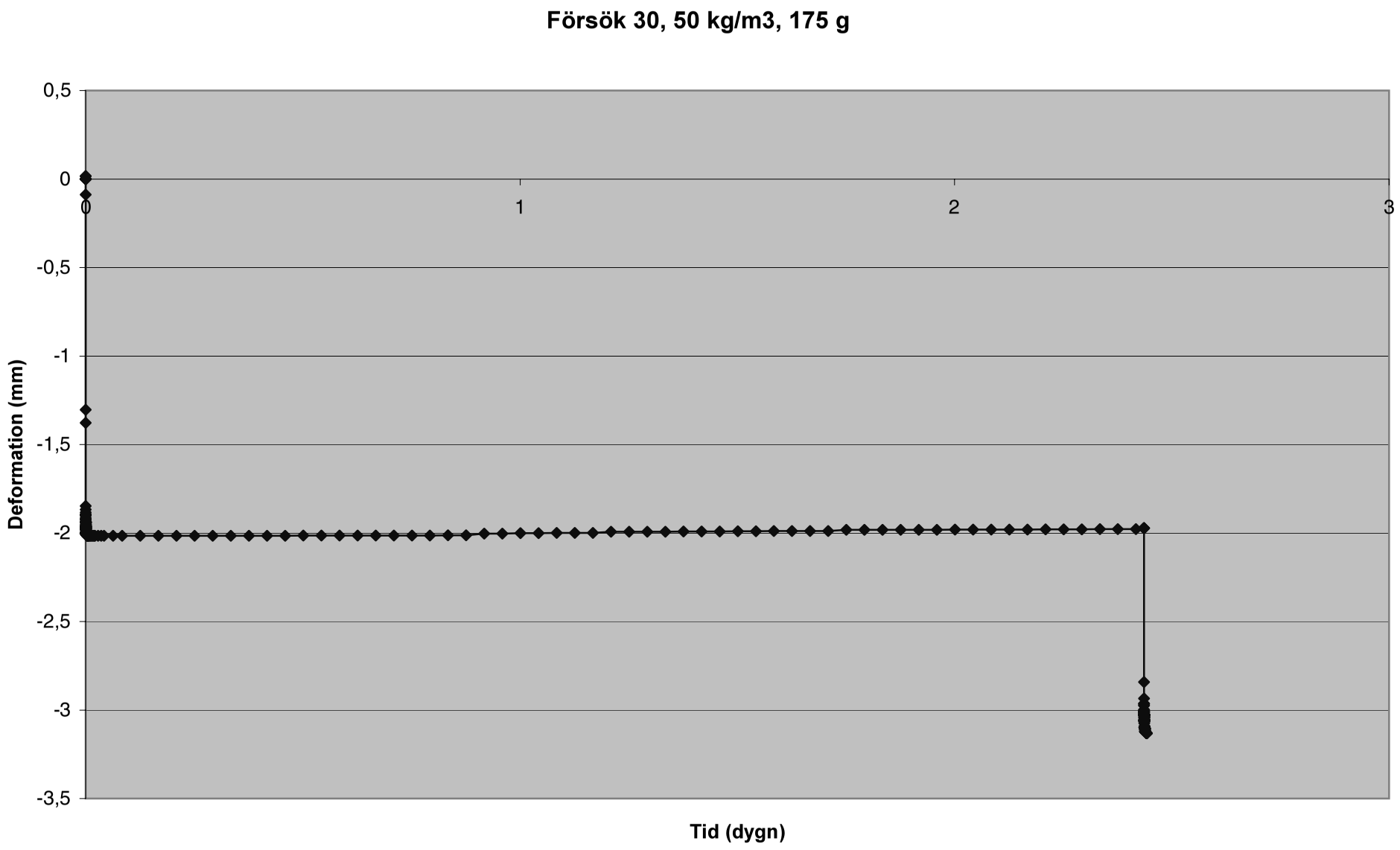
-1,5
-2
-2,5
-3
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 30, 50 kg/m3, 175 g
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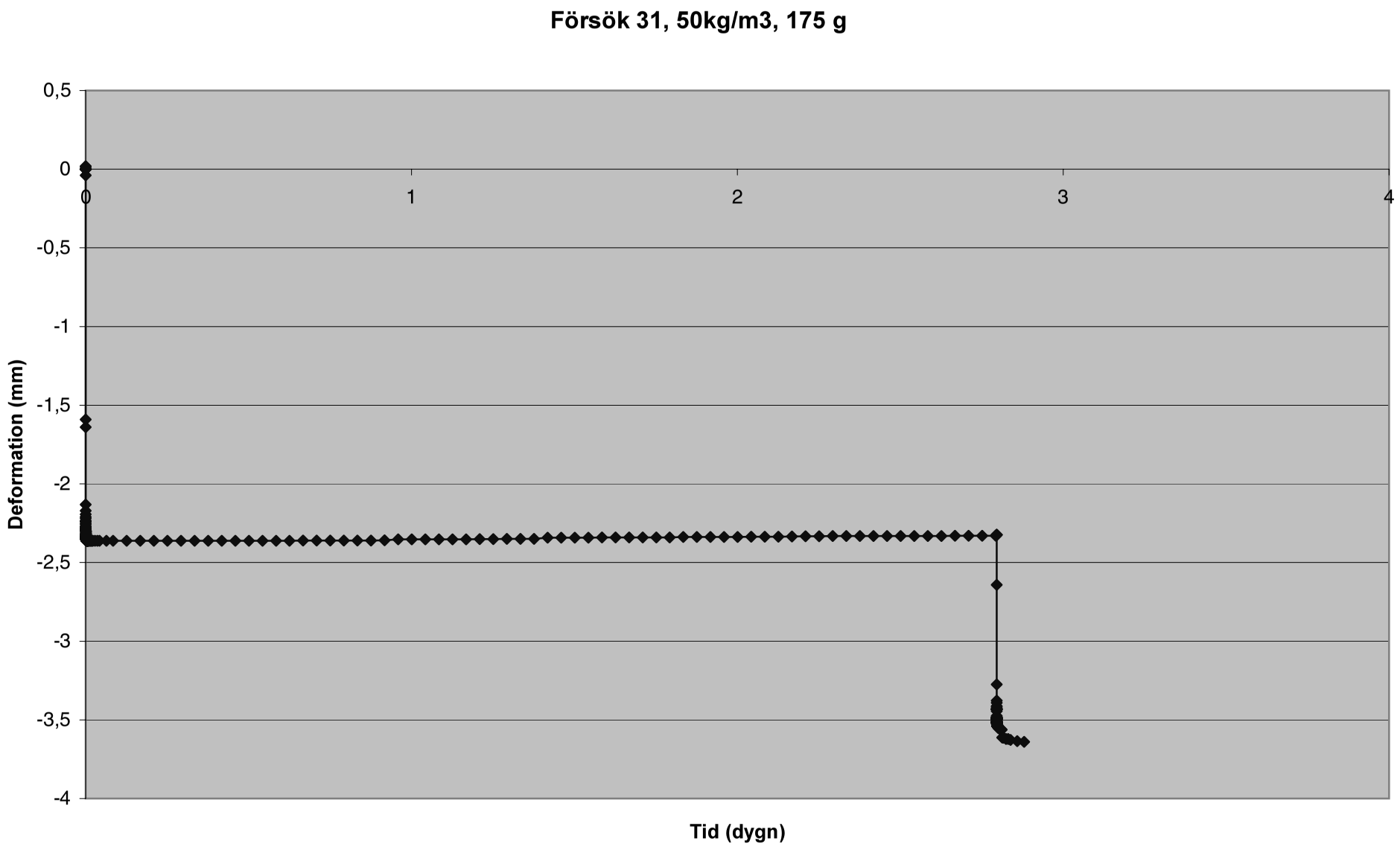
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
0
1
2
3
Deformation (mm)
Tid (dygn)


Försök 31, 50kg/m3, 175 g
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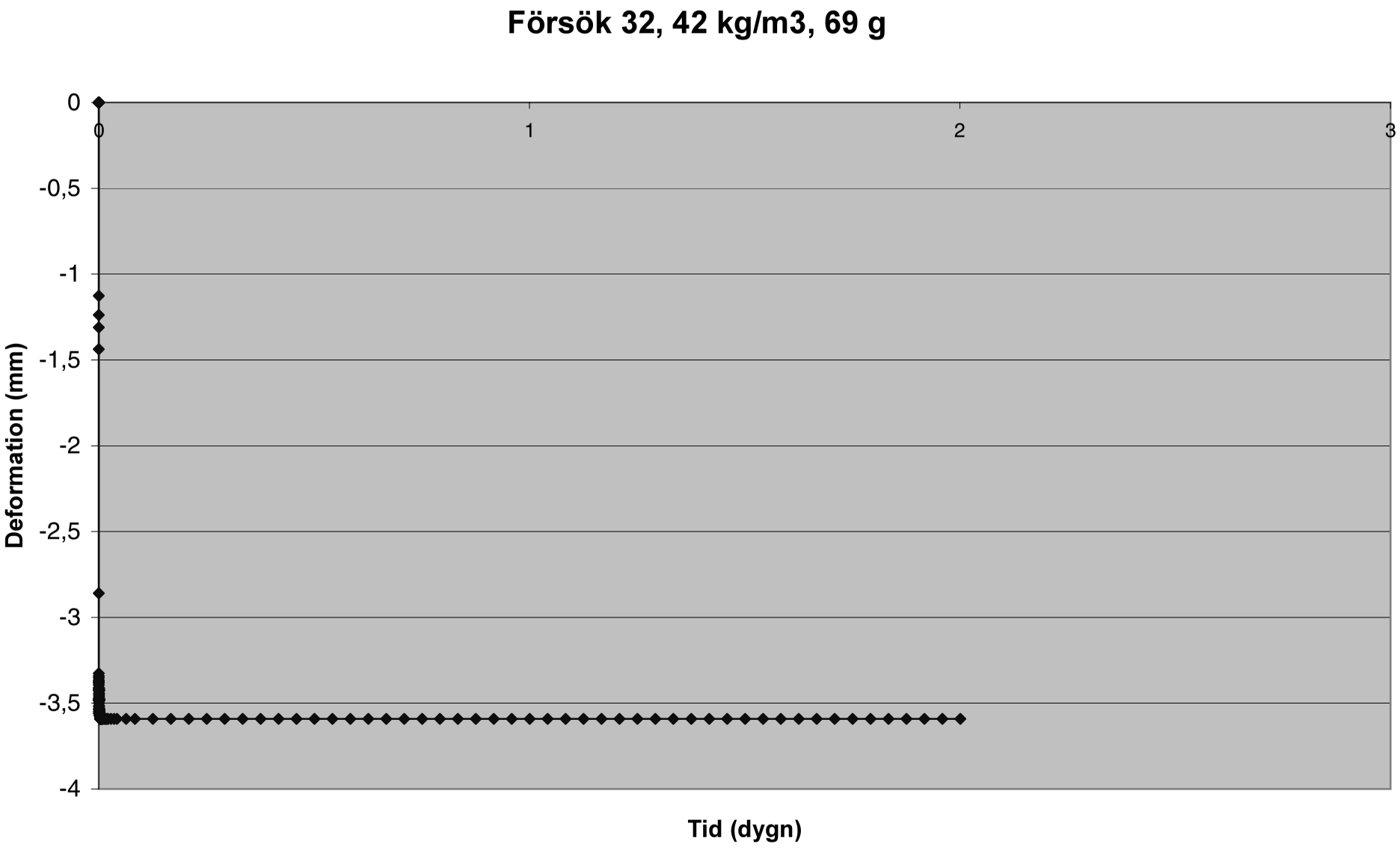
0
-0,5
-1
-1,5
-2
-2,5
-3
-3,5
-4
0
1
2
3
4
Deformation (mm)
Tid (dygn)


Försök 32, 42 kg/m3, 69 g
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-2,5
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-3,5
-4
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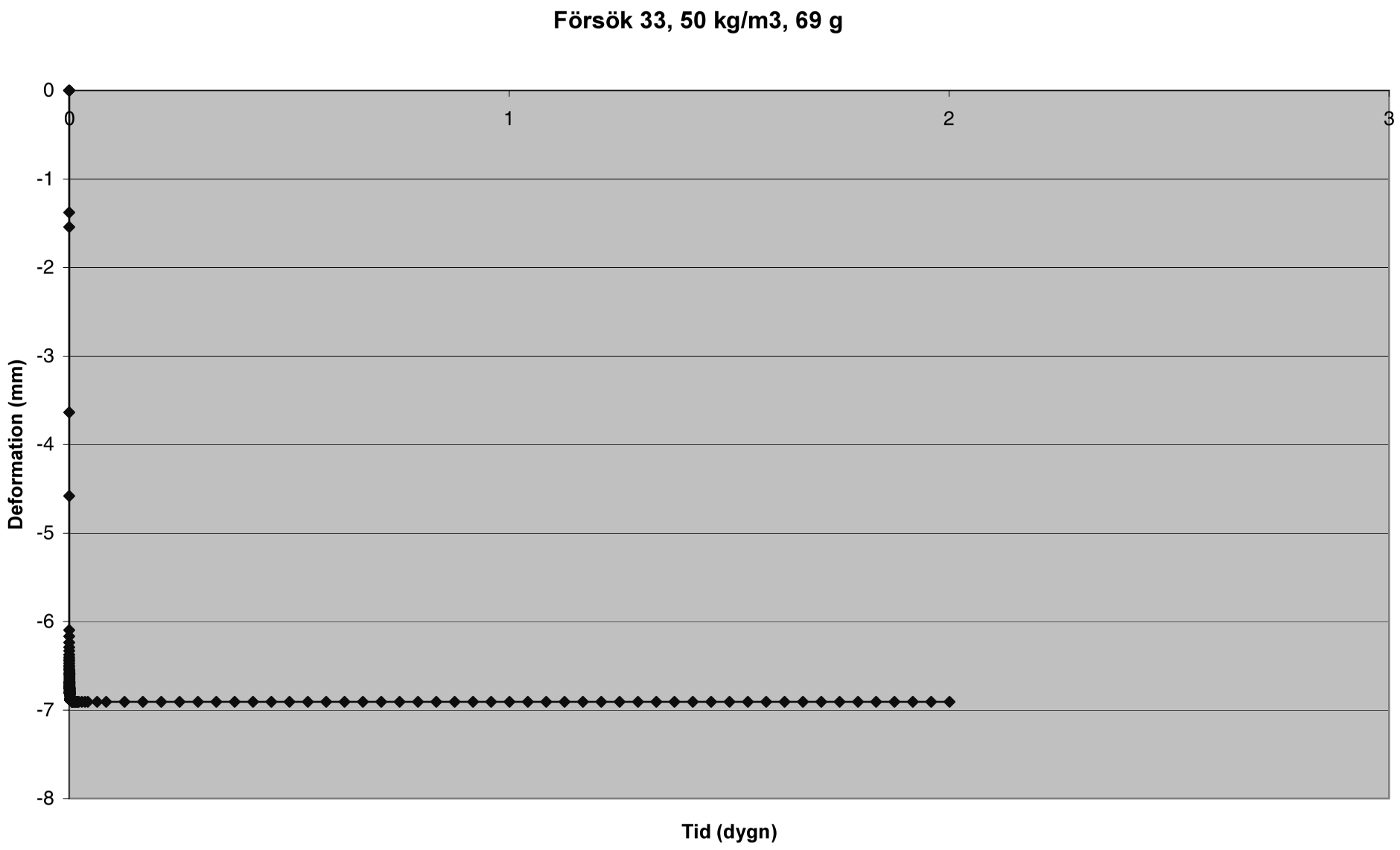
1
2
3
Deformation (mm)
Tid (dygn)


Försök 33, 50 kg/m3, 69 g
0
-1
-2
-3
-4
-5
-6
-7
-8
0
1
2
3
Deformation (mm)
Tid (dygn)

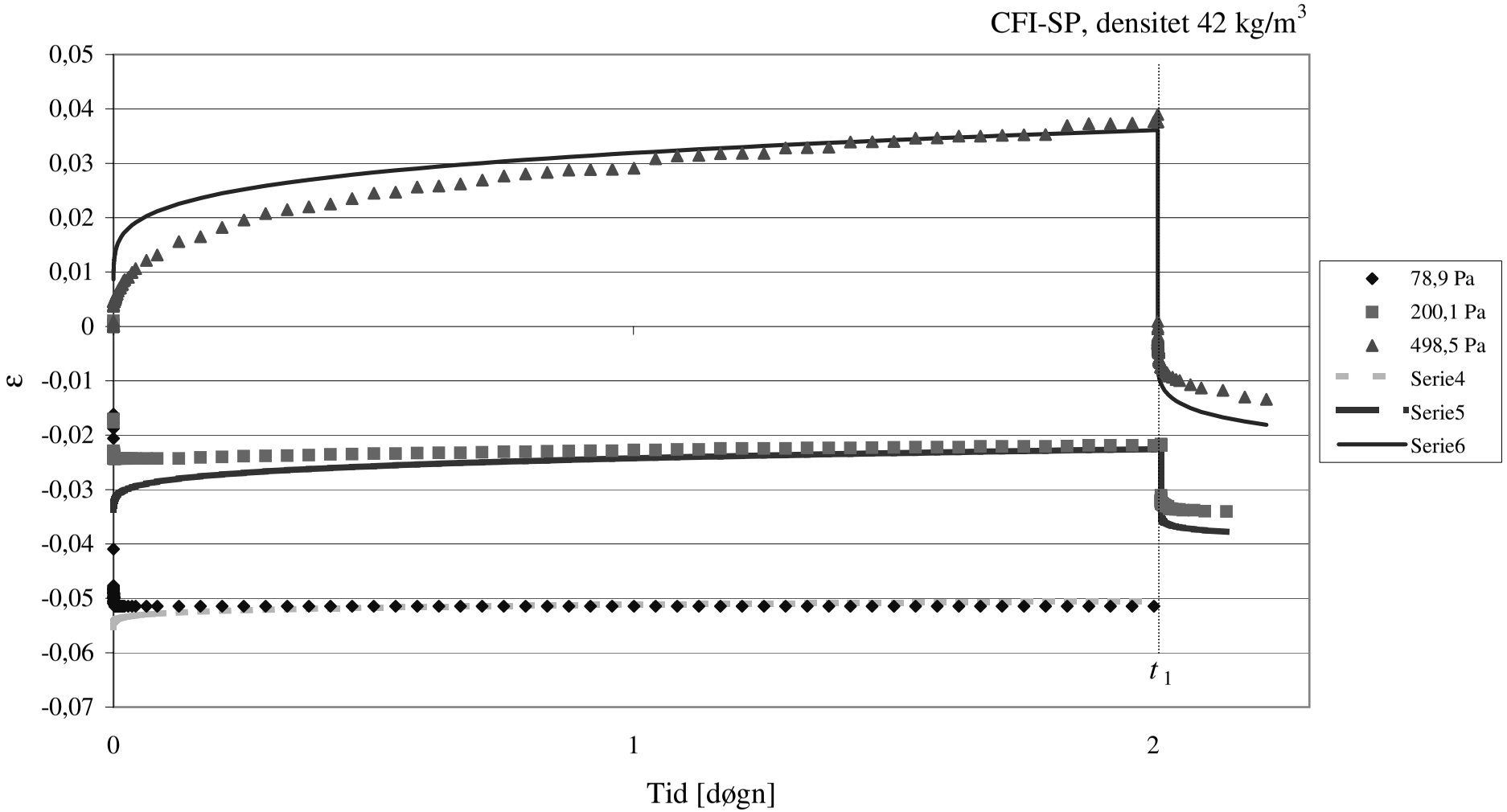
Appendix D

Strain-time diagram for CFI-SP, density 42 kg/m^3

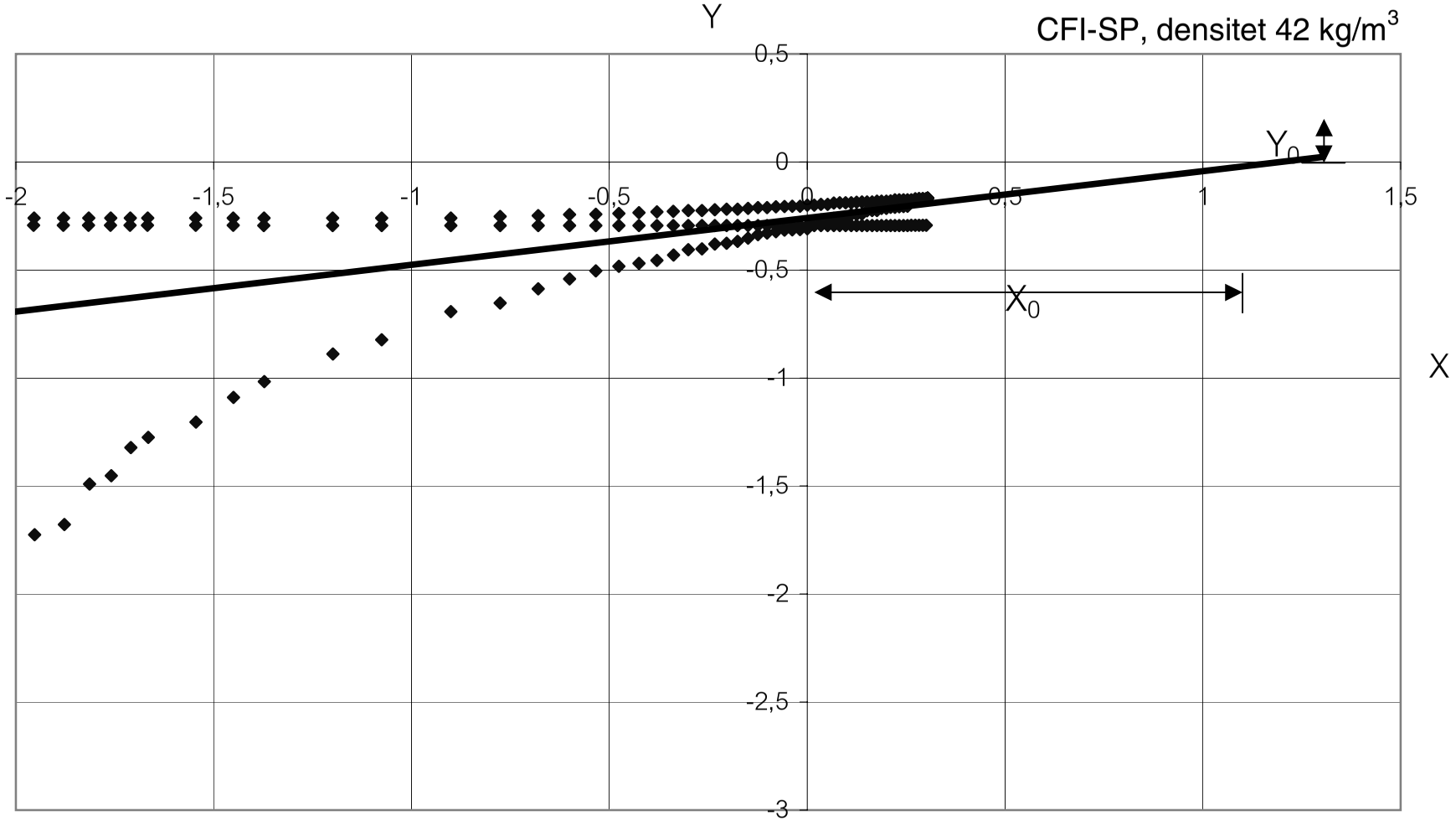
X and Y shown in a logarithm diagram

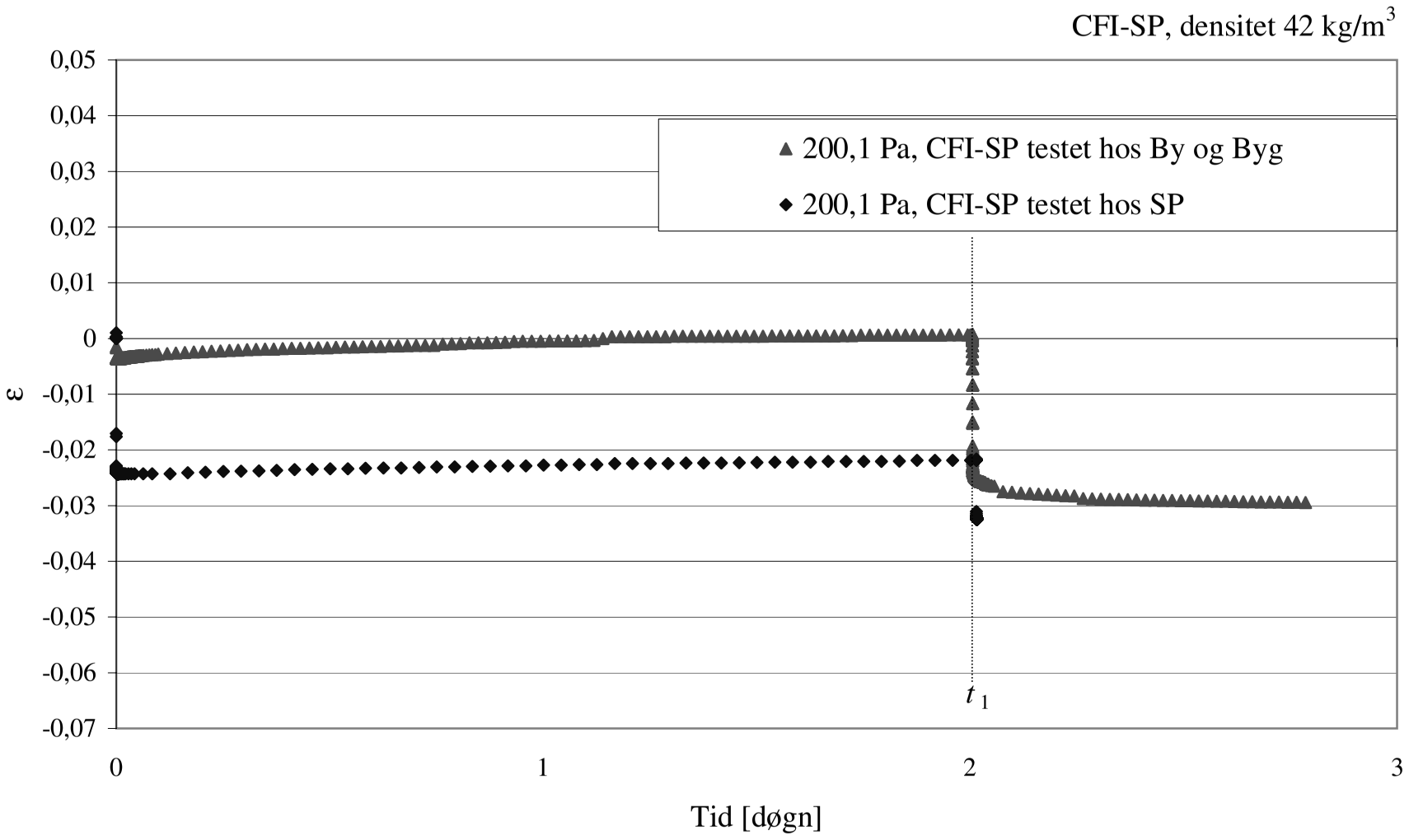
Parallel test at SP and By og Byg: Strain-time diagram for CFI-SP, density 42 kg/m^3, load 200,1 Pa

Målt samt beregnet krybning for RH = 50%, Temp. = 23 °C



Målt krybning for RH = 50%, Temp. = 23 °C




Målt krybning for RH = 50%, Temp. = 23 °C
CFI-SP, densitet 42 kg/m3
200,1 Pa, CFI-SP testet hos By og Byg
200,1 Pa, CFI-SP testet hos SP
0,05
0,04
0,03
0,02
0,01
0
-0,01
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-0,05
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Appendix E

VTT report

Requested by

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Civilingeniør Ph.D. Seniorforsker
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Order

Nordtest project 1536-01.

Contact person at VTT

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Task

Test and modelling of creep

Sample

Loose fill cellulose insulation. Sample was received from By-og-byg, Denmark (Torben Valdbjørn Rasmussen).

General

Within the nordtest projekt "Granulaere isoleringsmaterialers krybning – Metodebeskrivelse og samkalibrering" (Nordtest project nr 1536-01) the proposed standard for measuring and modelling creep of insulation materials is tested by carrying out a "round-robin" test in three laboratories for a given material. VTT Building and Transport was one of the three laboratories.

Performance of the task

The test was carried out according to the standard (draft) LOOSE-FILL INSULATION IN WALLS - TEST AND MODELLING OF CREEP (Based on By og Byg Documentation 011, "Sætningsfri indblæsning af løsfyldesisolering i vægge", Danish Building and Urban Research, 2001), dated 16.08.2001.

The samples were maintained at 50% rh and 23°C for 1 month before carrying out the task and during the tests. Each of the nine tests had a new test sample.

The measurements were carried out for the following set of density and load:

- density 42 kg/m^3 mounted 78 Pa (date 21-23.9.2001, no unloading test)
  42 kg/m^3 mounted 202 Pa (date 24-27.9.2001)
  42 kg/m^3 mounted 499 Pa (date 28.9-1.10.2001)

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- density 50 kg/m^3 mounted 78 Pa (date 1-3.10.2001, no unloading test)
  50 kg/m^3 mounted 202 Pa (date 5-8.10.2001)
  50 kg/m^3 mounted 499 Pa (date 8-11.10.2001)

- density 60 kg/m^3 mounted 78 Pa (date 12-15.10.2001, no unloading test)
  60 kg/m^3 mounted 202 Pa (date 15-18.10.2001)
  60 kg/m^3 mounted 499 Pa (date 19-22.10.2001).

At the beginning of the test the reading of the test device was zero. Then the load was released by removing the sticks. The measurement for loading lasted three days after which the load was removed and the recovery (expansion) of the insulation was measured for 2 hours.

The test equipment was built at VTT Building and Transport according to the instructions given in the standard (draft) LOOSE-FILL INSULATION IN WALLS - TEST AND MODELLING OF CREEP.

Inaccuracy

The equipment that was used to measure the creep was made by Mitutoyo Corp. (Japan), model ID-C1050B. The accuracy is 0.01 mm. The string was removed from the device in order to avoid additional load to the test specimen.

Test results

Results are given in Figures 1-3 and Table 1.

The values for the Clouser equation $c(t)=1/E*(1+(t/\tau)^b)+C_1$ for different densities are given Table 1.

Table 1. Parameters determined for the Clouser equation.

Density, kg/m^3 - load	**E**	**τ**	**b**	**C_1**
42	13332	52935	0.2523	
78 Pa				0.0004267288
202 Pa				0.0004236923
499 Pa				0.0002552140
50	13332	457317	0.2481	
78 Pa				-0.0001140370
202 Pa				0.0001285639
499 Pa				0.0001373405
60	20600	114092	0.1502	
78 Pa				-0.0001387231
202 Pa				-0.0000511108
499 Pa				0.0000815762

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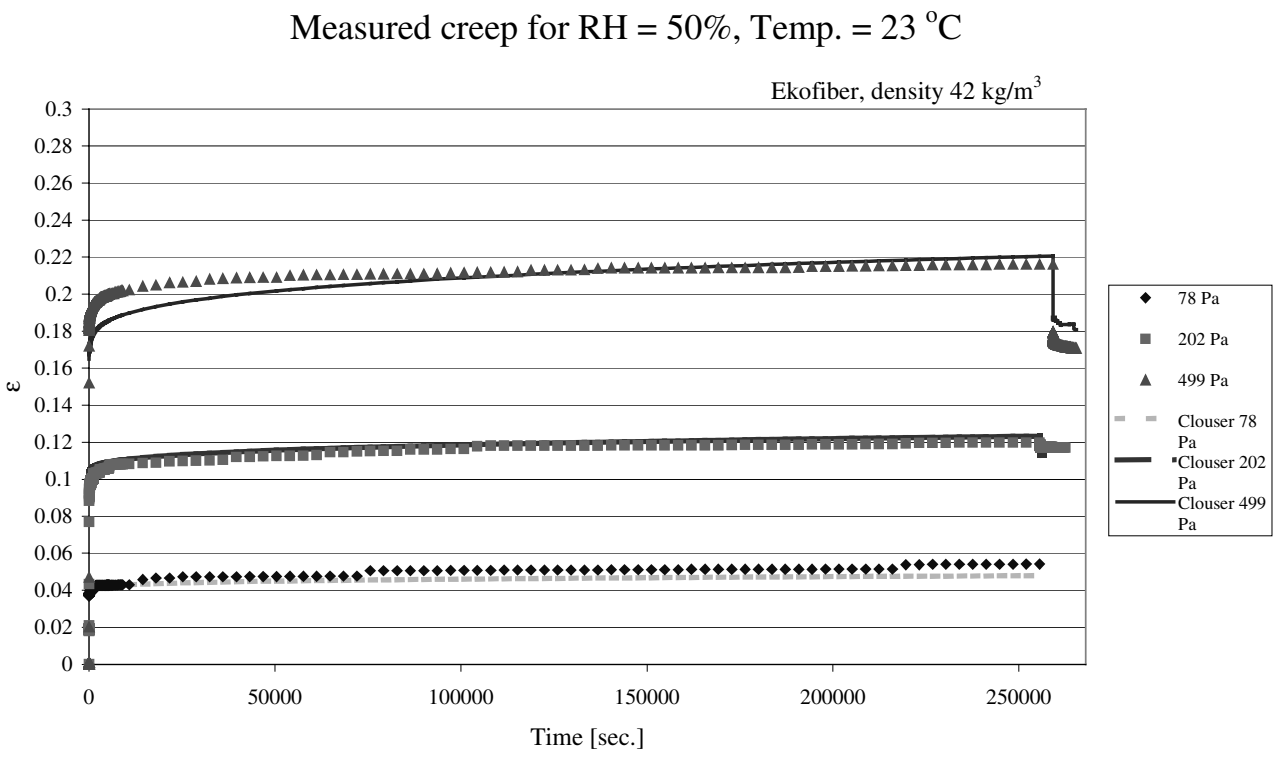

Figure 1a. Measured strain time curve and the adjusted Clouser equation for density 42 kg/m^3 at 23°C, 50%-rh.

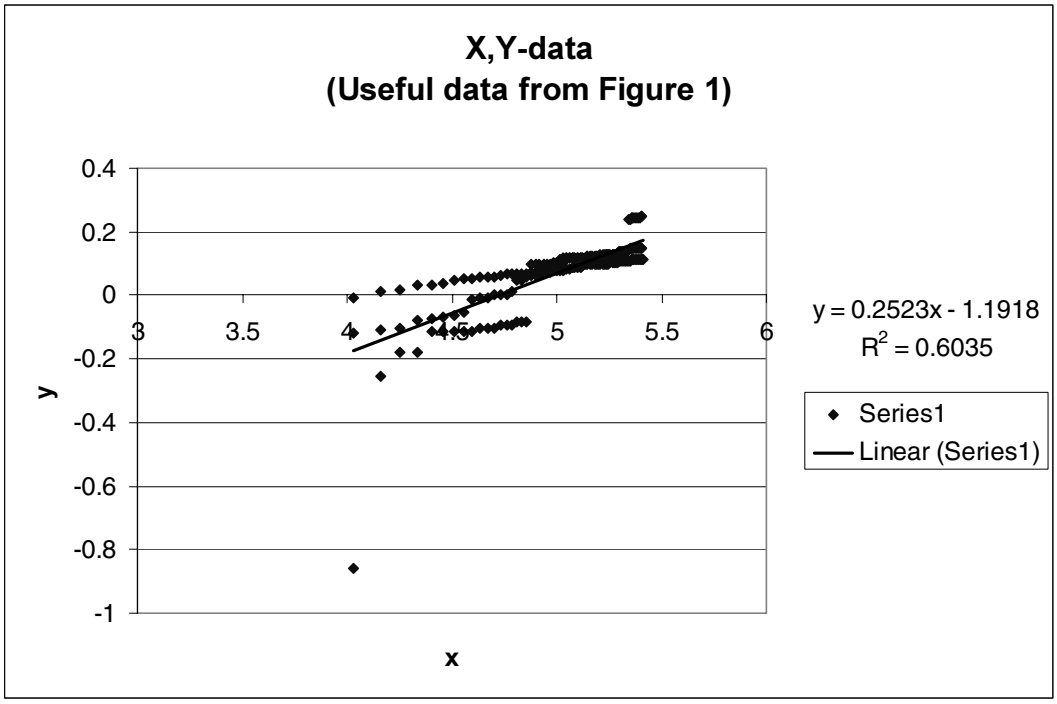

Figure 1b. X-Y-data for Clouser function: density 42 kg/m^3 at 23°C, 50%-rh.

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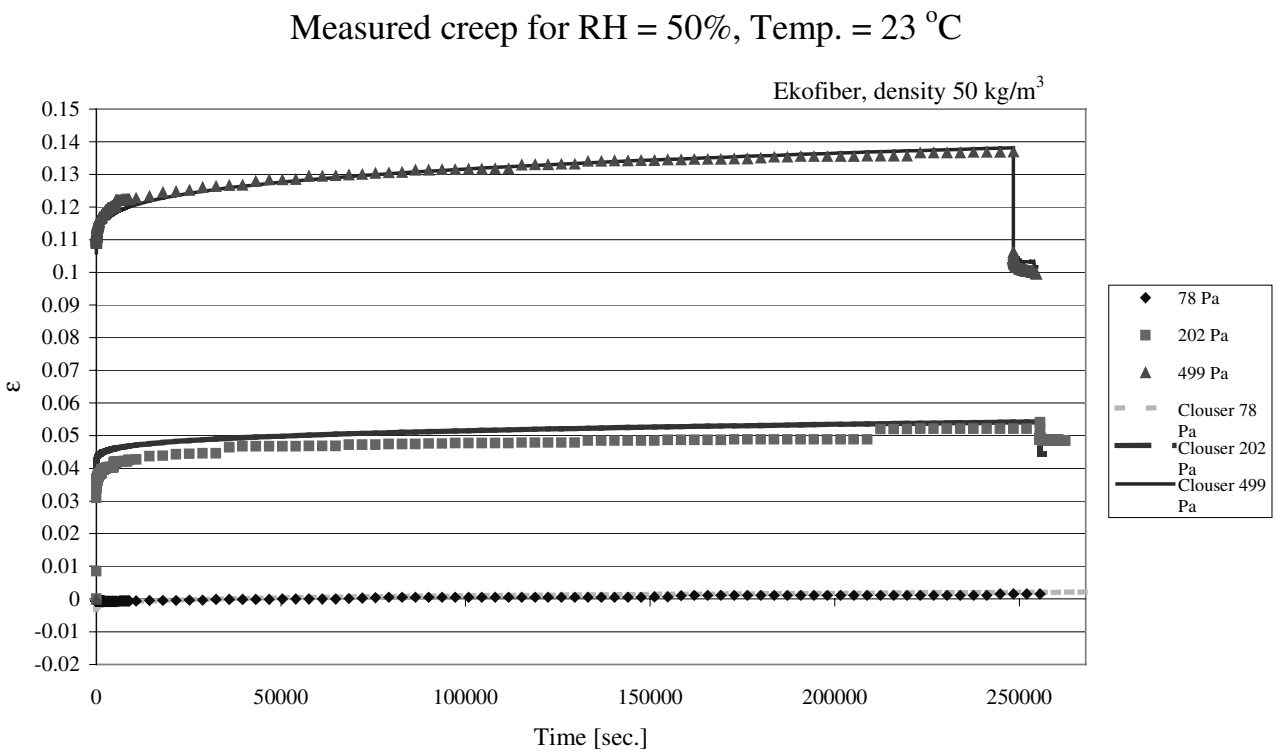

Figure 2a. Measured strain time curve and the adjusted Clouser equation for density 50 kg/m^3 at 23°C, 50%-rh.

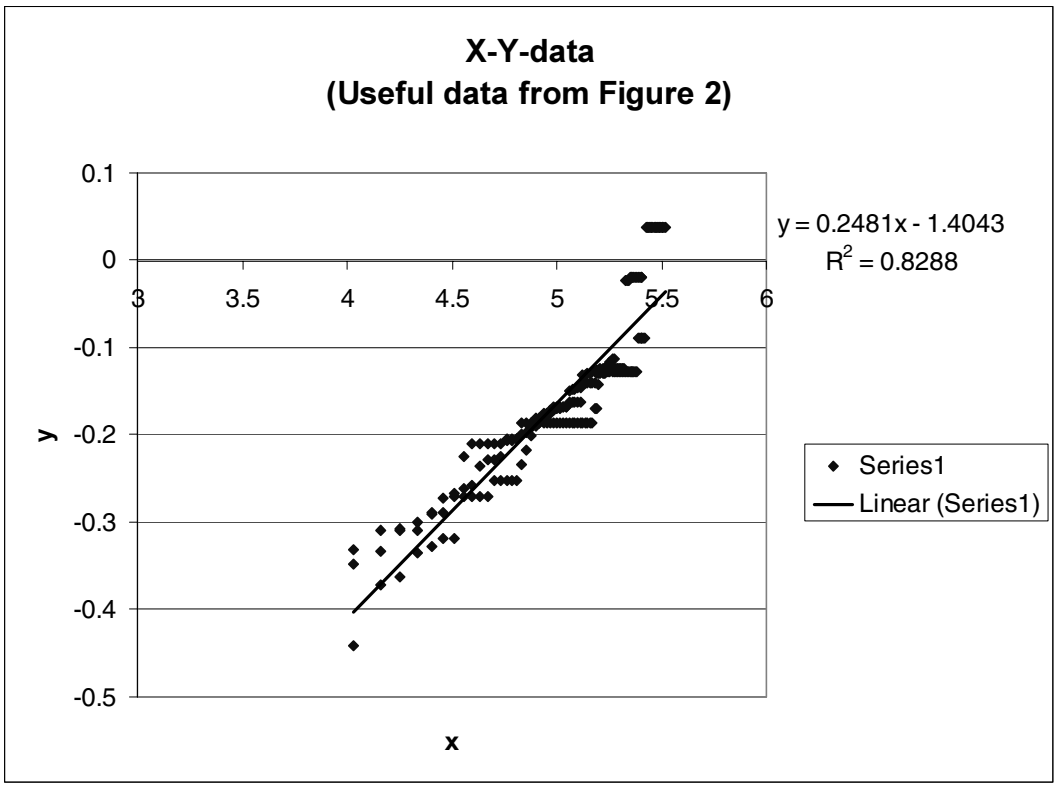

Figure 2b. X-Y-data for Clouser function: density 50 kg/m^3 at 23°C, 50%-rh.

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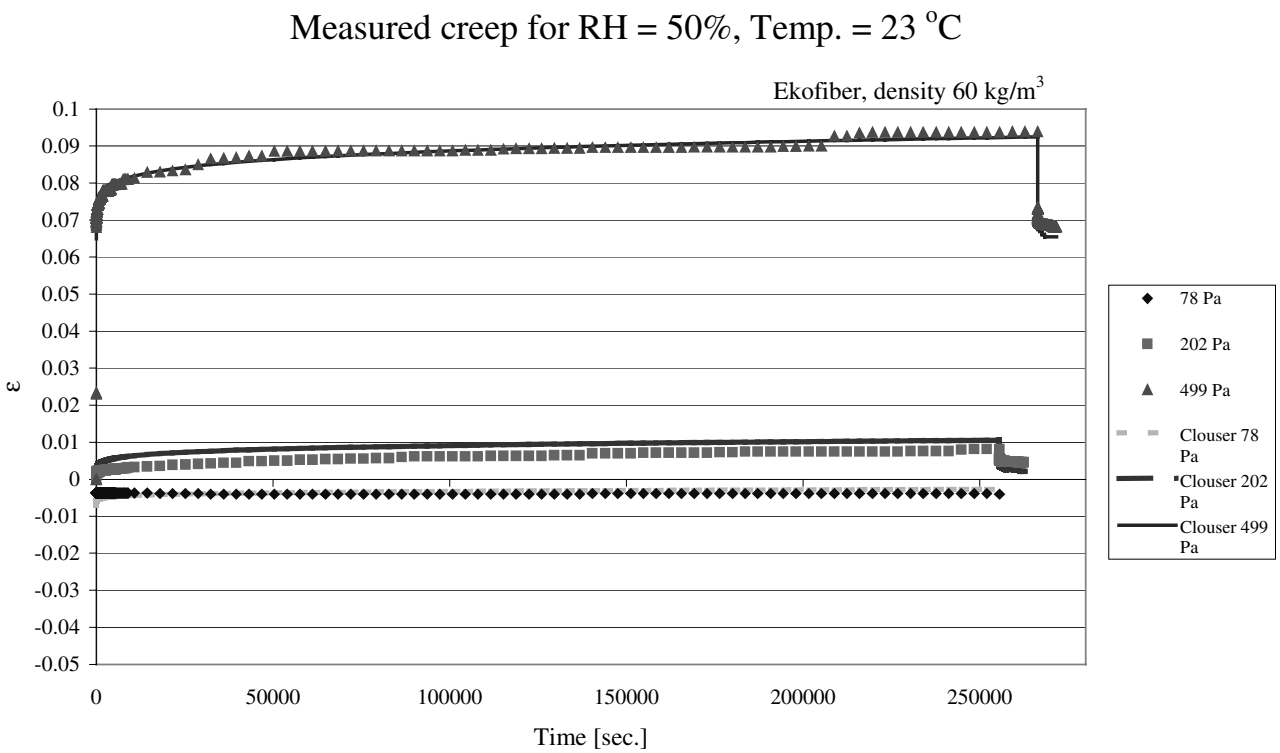

Figure 3a. Measured strain time curve and the adjusted Clouser equation for density 60 kg/m^3 at 23°C, 50%-rh.

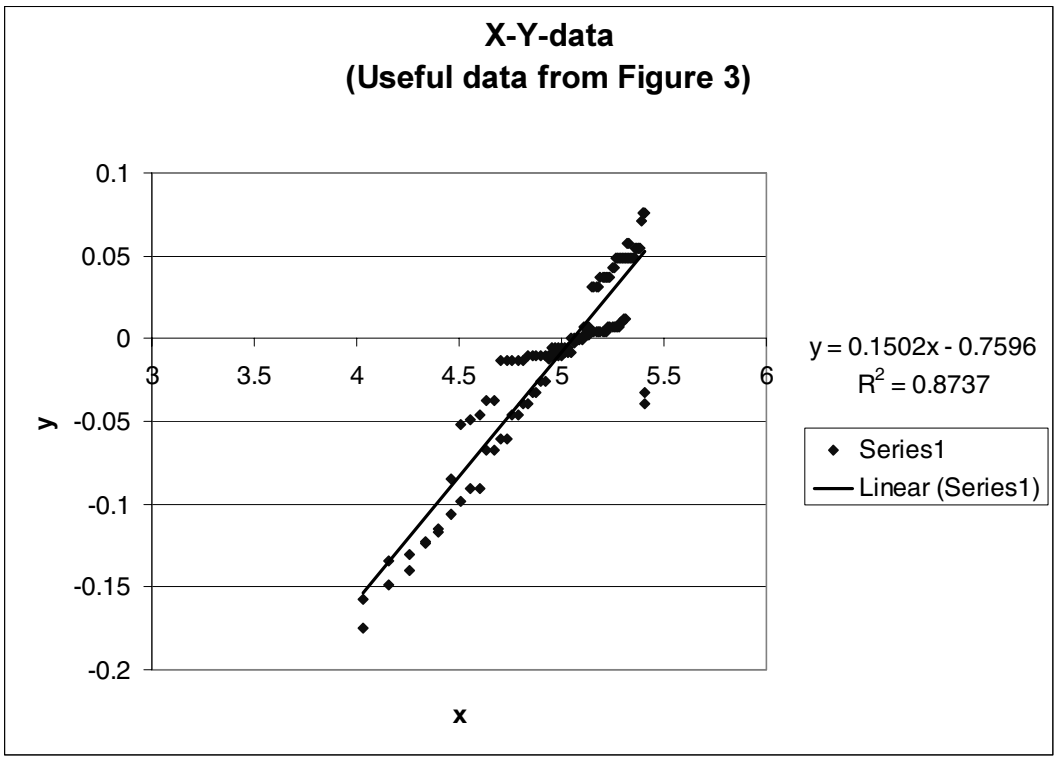

Figure 3b. X-Y-data for Clouser function: density 60 kg/m^3 at 23°C, 50%-rh.

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Espoo, 26.11.2001

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Research Scientist

Hannu Hyttinen
Research Engineer

APPENDICES

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The use of the name of the Technical Research Centre of Finland (VTT) in advertising or publication of this report in part is possible only by written permission from VTT.

This report presents a proposal for a standardised method for creep tests and the necessary theoretical framework that can be used to describe creep of a granulated loose-fill material. Furthermore results from a round robin test are shown. The round robin test was carried out in collaboration with SP-Building Physics in Sweden and VTT Building Technology in Finland. For the round robin test a cellulosic fibre insulation material was used. The proposed standardised method for creep tests and theories are limited to cases when the granulated loose-fill material is exposed to a constant environment with a constant temperature and a constant relative humidity.
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.

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