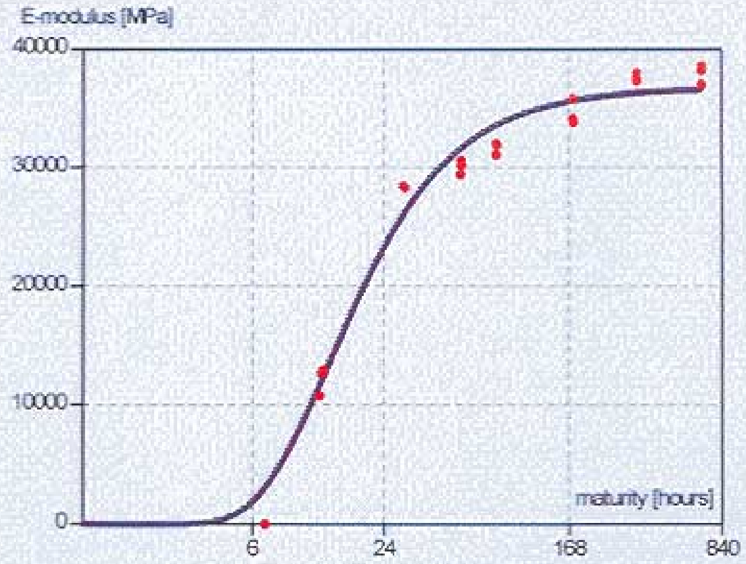
HETEK

Control of Early Age Cracking in Concrete Phase 6: Early Age Properties of Alternative Concrete



Report No.114
1997

Road Directorate Denmark Ministry of Transport

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	Modulus of Elasticity	5919
	Heat	6743
	Development	9013
	Shrinkage	4743
	Splitting tensile test	6249
	Coefficient	6410
	Research Project	8557
	Denmark	8028

Abstract

This report forms a part of the Danish Road Directorate's research programme called High Performance Concrete - The Contractor's Technology (abbreviated to HETEK).

This report determines the early age properties of an alternative concrete. The test programme used corresponds to the one used in practice for the time being (February 1997). The properties regarded are:

- Heat development
- E-modulus and compressive strength development
- Splitting tensile strength development
- Thermal expansion coefficient
- Shrinkage in early age
- Creep in early age

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0. Preface

This project on control of early age cracking is part of the Danish Road Directorate's research programme, High Performance Concrete - The Contractor's Technology, [1] abbreviated to HETEK.

In this programme high performance concrete is defined as concrete with a service life in excess of 100 years in an aggressive environment.

The research programme includes investigations concerning the contractor's design of high performance concrete and execution of the concrete work with reference to the required service life of 100 years.

The total HETEK research programme is divided into segments parts with the following topics:

- chloride penetration
- frost resistance
- control of early-age cracking
- compaction
- curing (evaporation protection)
- trial casting
- repair of defects.

The Danish Road Directorate invited tenders for this research programme which is mainly financed by the Danish Ministry for Commerce and Industry - The Commission of Research and Development Contracts.

The present report referes to the part of the HETEK project which deals with control of early age cracking.

For durability reasons reinforced structural members should be well protected against penetration of water, chloride etc. This means that cracks should be avoided or at least the crack-width limited. Formation of cracks can take place already during the hardening process. An evaluation of the risk of crack formation involves a stress analysis. In stress analysis of hardening concrete structures, the load consists of the differences in thermal strains that arise from the heat of hydration. The mechanical properties (including autogenous shrinkage) of the concrete also change during the hardening process. If a stress analysis shows high stresses compared to the tensile strength there is a high risk of crack formation.

In Danish: Højkvalitetsbeton - Entreprenørens Teknologi

The purpose of this project is to investigate these effects and to prepare a guideline regarding Control of Early Age Cracking.

The project was carried out by a consortium consisting of:

Danish Concrete Institute represented by:

Højgaard & Schultz A/S
Monberg & Thorsen A/S
RAMBØLL
COWI

and

Danish Technological Institute, represented by the Concrete Centre

and

Technical University of Denmark, represented represented by the Department of Structural Engineering and Materials.

Two external consultants, professor Per Freiesleben Hansen and manager Jens Frandsen, are connected with the consortium.

The present report on "Early Age Porperties of Alternative Concrete" has been carried out at Danish Technological Institute, the Concrete Centre except for the part concerning creep at variable temperature and a test with fixed strain subjected to a temperature history which have been carried out at the Technical University of Denmark. These parts are reported in appendix 15.

1. Objective

This report determines the early age properties of a selected concrete as described below. The test programme used corresponds to the one used in practice for the time being (February 1997).

The properties regarded are:

- Heat development
- E-modulus and compressive strength development
- Splitting tensile strength development
- Thermal expansion coefficient
- Shrinkage in early age
- Creep in early age

In addition a creep test at variable temperature and a test with aimed fixed strain subjected to a temperature history have been carried out. These parts are reported in appendix 15 and evaluated in the report "Material Modelling, Continuum Approach", [Hauggaard, 1997].

The HETEK project deals with High Performance Concrete defined as concrete with a service life in excess of 100 years in an aggressive environment e.g. marine, with salt and frost.

The Danish Road Directorate normally prescribes a maximum w/c-ratio of 0.45 for concrete in exposure class A (aggressive) with a minimum content of cement on 275 kg/m^3. Furtermore, the type of cement shall be a low-alkali sulfatresistent cement. This type of concrete used for bridges in general.

The Basic Concrete Specification for Building Structure allows all types of cement for concrete in exposure class A. Therefore it has been decided to use a concrete with a portland limestone cement (named Basis-Cement) which have a maximum w/c-ratio of 0.45 and a minimum content of cement of 311 kg/m^3. As addition fly ash and silica fume will be used. This type of concrete corresponds to the concrete which will be used for bridges in general if there was not a limitation on the type of cement.

2. Test Methods

The following test methods have been used:

DS423.12 (March 1984)	Consistency of fresh concrete. Slump test.
DS423.15 (March 1984)	Determination of the content of airvoid in fresh concrete.
DS423.16 (March 1984)	Fresh concrete. Density.
DS423.23 (March 1984)	Hardened concrete. Compressive Strength.
DS423.25 (March 1984)	Hardened concrete. Modulus of Elasticity.
DS423.34 (January 1985)	Tensile strength deduced from splitting test on cylindical specimens
NT Build 388. (1992)	Heat Development.
TI-B 101 (Sept. 1994)	Test Method. Concrete. Thermal Expansion Coefficient.
TI-B 102 (Nov. 1995)	Test Method. Concrete. Strains from creep and shrinkage in early ages.

The test methods TI-B 101 and TI-B 102 are enclosed in appendices 13 and 14.

3. Concrete

The concrete used was concrete A35BSFAA25DS from Unicon I/S (Delivery note no. 25-65703). The concrete composition is shown in table 1. The mix report is shown in appendix 1. The equivalent w/c-ratio is 0.41, calculated as water/(cement + 2·micro silica fume + 0.5·fly ash). This concrete mainly differs from the concrete tested in another part of the HETEK-project [Spange, 1996] by the type of cement used.

The concrete was mixed at Unicon, Hedehusene and transported to DTI, Taastrup where the specimens were cast. The transportation time was app. 40 min.

Table 1: Mix design

Mix design			
	Type/origin/class	kg/m³	
Cement	Basis CEM II/A - L 52,5 R (IS/LA/≤2)	321	1)
Flyash	Danaske	61	1)
Silica fume	-	20	1)
Water	Water	156	2)
Fine aggregate	RN, Avedøre sand 0/4, SA	553	3)
Coarse aggregate	Dalby granite 4/16, A	712	3)
Coarse aggregate	Dalby granite 16/25, A	489	3)
Air entrainment	Sika Aer - 15B	1.89	4)
Plasticiser	Sika Plastiment - A40	2.82	5)

1) Dry
2) Added water + free water content of aggregates. The quantity of water does not include the water content of plasticizer and air entrainment.
3) Water-saturated surface - dry.
4) The quantity includes water content (97 % of the stated value).
5) The quantity includes water content (60 % of the stated value).

It should be noted that the concrete used for the tests reported in appendix 15 was mixed at DTU.

4. Test Specimens

For determination of E-modulus and strength developments 49 cylinders D150 x h300 mm were cast. Further, 1 cylinder D150 x h300 mm was cast with a thermocouple in the center of the cylinder thus the maturity of the cylinders could be determined.

For determination of thermal expansion coefficient according to TI-B101 3 prisms - 100x100x400 mm were cast. In one of the prisms a thermocouple was placed.

For determination of shrinkage and creep 6 cylinders D130 x h700 mm were cast. Specimen 1-3 were loaded and specimen 4-6 remained unloaded. The concrete temperature was measured in specimen 5. Furthermore the air temperature was measured.

5. Results

5.1 Properties of fresh concrete

Time of mixing was 1996-11-05 at 7:47. The concrete arrived at DTI 1996-11-05 at 8:26. Slump, air content, density and temperature were measured at Unicon and just after arrival at DTI. The results are shown in table 2.

Table 2: Properties of fresh concrete measured before transportation and just after arrival at DTI.

Measured at	Slump [mm]	Air content [%]	Density [kg/m^3]	Temp. [°C]
Unicon	110	5.9	2330	18.0
DTI	80	2.6	2430	16.0

5.2 Heat development

The heat development was determined on 5 samples. The results are shown in appendix 2. The main results are shown in table 3.

Table 3: Heat development (ref. appendix 2).

$$Q(M) = Q_\infty \cdot \exp\left(-\left(\frac{\tau_e}{M}\right)^\alpha\right)$$

	Q_∞ kJ/kg cement 1)	Q_∞ kg/kg cement + min.add. 2)	τ_e [hour]	α [-]	τ_0 [hour]
Mean	420.6	338.3	15.4	1.23	6.8
St. dev.	11.3	9.1	0.37	0.04	0.12

1) Corresponding content of cement = 319.9 kg/m^3
2) Corresponding content of cement + min. add. = 397.7 kg/m^3

The mix design stated in the test report of appendix 2 differs a little from the one stated in table 1. The values in appendix 2 are based on the actual values stated in the delivery note (appendix 1) compensated for the air content measured at DTI. The densities used are the densities normally used at DTI.

5.3 Thermal expansion coefficient

The thermal expansion coefficient was determined according to TI-B 101 at 1, 3 and 7 days. The results are shown in appendix 3. The main results are shown in table 4.

Table 4: Thermal expansion coefficient according to TI-B 101 (ref. appendix 3).

Time [days]	1	3	7	mean
Th. exp.coef. [°C^{-1}]	$0.99 \cdot 10^{-5}$	$1.05 \cdot 10^{-5}$	$1.06 \cdot 10^{-5}$	$1.02 \cdot 10^{-5}$

5.4 E-modulus- and strength developments

E-modulus, compressive strength and splitting tensile strength was determined at ½, 1, 2, 3, 7, 14 and 28 days. The results of the E-modulus and compressive strength tests are shown in appendix 4. The results of the splitting tensile strength tests are shown in appendix 5. The parameters for description of the developments of the properties are shown in table 5. The parameters have been determined by regression.

Table 5: Parameters for description of developments (ref. appendices 4 and 5).

$$Property\ (M) = V_\infty \cdot \exp\left(-\left(\frac{\tau_e}{M}\right)^\alpha\right)$$

Property	V_∞	τ_e	α
E-modulus, E_0 [MPa]	37256	13.48	1.38
E-modulus, E_C [MPa]	36749	13.31	1.36
Comp. strength [MPa]	56.4	28.19	0.92
Split.tens. str. [MPa]	4.1	21.10	1.00

5.5 Shrinkage and Creep

The test specimens were cast 1996-11-05 at app. 8:51. The age and maturtity at time of casting and at start of measurings are shown in table 6. The setting time defined as τ_0 determined from the heat development was 6.8 hours.

Table 6: Age and maturity of specimens for creep and shrinkage test.

	Date / Time	Age [h]	Maturity [h]
Mixing	1996-11-05 / 7:47	0	0
Casting of specimens	1996-11-05 / 8:51	1.1	0.9
Start of measurings	1996-11-05 / 14:34	6.8	6.8

The results are shown in appendices 6-12. Time zero is at end of mixing.

The temperature in the concrete is measured in one of the specimens and shown in appendix 6.1 together with the calculated maturity as a function of time.

The measured air temperature is shown in appendix 6.2. It is seen to be app. 19.7°C except when the chamber is open at casting and at the first loading of each specimen. In these very short periods the maximum air temperature is seen to be app 21.4°C, which is under the temperature limit stated in TI-B 102. The maximum concrete temperature in the period of heat development is app. 27.4°C.

5.5.1 Shrinkage

The shrinkage as a function of maturity is shown in appendix 7.1. The determined shrinkage as a function of time for the three specimens is shown in appendix 7.2 together with the mean shrinkage.

The strains due to shrinkage is determined as the concrete strains in the specimens kept unloaded compensated for the strains due to deformations from temperature. In this compensation the temperature measured in specimen no. 5 is used together with a thermal expansion coefficient of $1.02 \cdot 10^{-5} {}^\circ C^{-1}$ (table 4). The thermal expansion coefficient is assumed to be constant during the test period.

The measured concrete strain in each of the three specimens is shown in appendices 7.3-7.5 together with the temperature compensated strain.

In stress calculations of hardening concrete structures the shrinkage can be described by an idealised curve given by the values of maturity and strain shown in table 6. This idealised curve is shown in appendix 7.1 together with the measured shrinkage.

Table 6: Strains to describe shrinkage in stress calculations.

Maturity [hours]	Strain [m/m]	Maturity [hours]	Strain [m/m]
0	0	214	-0.0000810
7	0	252	-0.0000900
8	-0.0000090	336	-0.0001080
10	-0.0000580	420	-0.0001200
16	-0.0000960	504	-0.0001280
28	-0.0001050	588	-0.0001370
72	-0.0000920	672	-0.0001460
120	-0.0000810	756	-0.0001520
144	-0.0000810	780	-0.0001510
168	-0.0000770	840	-0.0001560
192	-0.0000810	868	-0.0001600

5.5.2 Creep

The concrete strain in the loaded specimens as a function of time is shown in appendices 8.1-8.3 together with the part of the strain which is due to external load. The strain from external load is determined as the measured concrete strain compensated for deformations due to shrinkage and temperature. The compensation is based on the measurings on the 3 specimens kept unloaded.

The load histories are shown in appendices 9.1-9.3. The load level is chosen as app. 40% of the expected compressive strength. The maximum load which can be applied corresponds to app. 16 MPa. At load times where the strength was not determined, the strength was estimated using the knowledge from the strength development.

The creep strains as a function of time for specimen 1-3 are shown in appendices 10.1-10.3. The creep strains have been determined as the strains in the loaded specimens compensated for temperature deformations, shrinkage and initial elastic deformations.

In the compensation of the initial elastic strains, the idealised load histories shown in appendices 9.1-9.3 and table 7 are used. The E-modulus used is the E-modulus determined on the measurings during loading and unloading of the creep specimens (ref. table 8).

Table 7: Idealized load histories used in calculations of creep parameters.

Specimen 1		Specimen 2		Specimen 3	
Time [h]	load [Mpa]	Time [h]	load [MPa]	Time [h]	load [MPa]
0	0.04	0	0.05	0	0.25
12.10	1.53	12.17	1.29	-	-
-	-	28.69	0.28	28.74	8.90
54.07	12.59	54.04	12.40	54.02	0.29
-	-	77.57	0.23	77.60	13.34
-	-	108.26	13.60	108.24	0.29
-	-	146.09	0.23	146.12	13.67
176.02	15.73	-	-	-	-
-	-	223.67	16.54	223.64	0.27
-	-	315.07	0.25	315.09	16.47
338.51	16.58	-	-	-	-
-	-	389.26	16.48	389.22	0.28
-	-	483.29	0.25	483.32	16.39
-	-	649.32	16.42	649.29	0.13
746.16	0.00	746.12	0.01	-	-

Table 8: E-modulus determined during loading and unloading of creep specimens. Used in calculation of creep parameters.

Specimen 1			Specimen 2			Specimen 3		
Time [h]	Matu-rity [h]	E [MPa]	Time [h]	Matu-rity [h]	E [MPa]	Time [h]	Matu-rity [h]	E [MPa]
12.10	13.2	14770	12.17	13.3	13610	-	-	-
-	-	-	28.69	33.1	31770	28.74	33.2	27890
54.07	59.8	32040	54.04	59.7	32210	54.02	59.7	34330
-	-	-	77.57	83.9	35420	77.60	83.9	34960
-	-	-	108.26	115.0	36150	108.24	115.0	36370
-	-	-	146.09	153.1	37390	146.12	153.1	36690
176.02	182.6	40350	-	-	-	-	-	-
-	-	-	223.67	230.3	38560	223.64	230.3	39100
-	-	-	315.07	321.9	39780	315.09	322.0	39880
338.51	345.5	44490	-	-	-	-	-	-
-	-	-	389.26	396.4	41060	389.22	396.3	41030
-	-	-	483.29	490.6	41860	483.32	490.6	41420
-	-	-	649.32	657.1	42740	649.29	657.1	42710
746.16	753.7	45110	746.12	753.7	43100	-	-	-

The creep parameters for use in stress calculations of hardening concrete structures are determined according to TI-B 102, Annex B with some modification as described in the following.

The creep model used can be described as a serial connection between a dashpot and a parallel connection of a dashpot and a spring. In this model the external dashpot represents the part of the creep, which causes irreversible deformations while the parallel connection represents the reversible deformations.

The development of the properties of the components are described by a function of the type

$$a+b\cdot\exp(-(c/\text{maturity})^d).$$

This function differs from the one suggested in in TI-B 102, Annex B.

The parameters are determined as described in [Pedersen, 1997]. The approach was made on the measurings during the first 28 days. The results are shown in table 9. The development of the properties are shown in appendix 11.

The parameters in table 9 describes the development of the properties as a function of maturity. The maturity is calculated as Maturity = 1.013 · Time.

The calculated strains of the specimens due to external load based on the parameters of table 9 are shown in appendices 12.1 - 12.3. In the calculation of the strains the E-modulus determined during the creep test (ref. table 8) is used together with the idealised load histories (ref. table 7).

Table 9: Parameters of creep model described in TI-B 102, Annex B.
η_1 is the viscosity of the external dashpot
η_2 is the viscosity of the dashpot in the parallel connection
E_2 is the spring constant

Property	**Function**	**a**	**b**	**c**	**d**
η_1 [MPa hours]	$a+b\cdot\exp[-(\frac{c}{M})^d]$	$0.9\cdot10^6$	$0.25\cdot10^9$	1418	0.5
η_2 [MPa hours]	$a+b\cdot\exp[-(\frac{c}{M})^d]$	$1.2\cdot10^6$	$0.135\cdot10^9$	3624	0.5
E_2 [MPa]	$a+b\cdot\exp[-(\frac{c}{M})^d]$	$0.152\cdot10^6$	$0.5\cdot10^6$	936	0.87

5.6 Tests carried out at DTU

The tests carried out at DTU are reported in appendix 15. It is seen that some problems occured concerning fixing the strain. The tests are evaluated in the report "Material Modelling, Continuum Approach", [Hauggaard, 1997].

6. Literature

Hauggaard, A. B. et al.: "HETEK - Control of Early Age Cracking in Concrete - Phase 3: Creep in Concrete", Danish Road Directorate, Report no. 111, 1997.

Hauggaard, A. B. et al.: "HETEK - Control of Early Age Cracking in Concrete - Phase 4 and 5: Material Modelling, Continuum Approach", Danish Road Directorate, Report no. 113, 1997.

Pedersen, E.S et al.: "HETEK - Control of Early Age Cracking in Concrete - Guidelines", Danish Road Directorate, Report no. 120, 1997.

Spange, H. and Pedersen, E.S: "HETEK - Control of Early Age Cracking in Concrete - Phase 1: Early Age Properties of Selected Concrete", Danish Road Directorate, Report no. 59, 1996.

APPENDIX 1

Concrete Composition

BETONKONTROLATTEST   UDSKRIFTSDATO: 05.11.96

R455 Vers. 2.4   UDTAGET DEN 05.11.96
KS-FORMULAR 4.10.5.01   NUMMER : 25-5594   SIDE 1

ORDRE :
KUNDE : UNICON BETON RUTH KNUDSEN
KØGEVEJ 172
4000 ROSKILDE

PLADS : GREGERSENSVEJ
DTI PORT 36 2630 TAASTRUP

RECEPT ..: A35BSFAA25DS
STYRKE ..: Fck 35 MPa
V/C PROP : Max
SÆTMÅL ..: 100
KITM.LUFT: Min. 15%
D.MAX ...: Dmax 25 mm
MILJØ KL : Aggressiv
BETONTYPE:

FABRIK.: HEDEHUSENE   BL.KL..: 07:47   BL.AF..: OEGE
FLG.SD.: 25-65703   LÆS M3.: 3.00   BIL NR.: 793
UDTAGET: Fabrik   UDT.KL.: 08:00   UDT.AF.: PAI

MATERIALE ART	MATERIALEKLASSE OG OPRINDELSE	FUGT %	DENS KG/M	TILS. BØR	BLAND ER	1 M3 BØR	V.O.T ER
CEMENT	Basis-cement	0.0	3100	962	966	321	320
FLYVEASKE	Danaske	0.0	2270	182	176	61	58
MICROSILI	Pulver Div.værker	0.0	2400	59	59	20	20
VAND	Vand	100.0	1000	377	377	156	156
LUFTINDBL	SikaAer-15B	97.0	1005	5.7	5.8	1.89	1.91
PLAST 1	Sika Plastiment-A40	60.0	1200	8.5	8.5	2.82	2.82
PLAST 2							
ANDET TSS							
SAND 1	RN-Avedøre 0- 4/A	1.6*	2615	1683	1688	553	550
SAND 2							
STEN 1	Dalby 4-16/A	1.1*	2750	2158	2152	712	705
STEN 2	Dalby 16-25/A	2.9*	2750	1509	1516	489	488
STEN 3							
TOTAL		KG		6944	6948	2315	2301
VOLUMEN		L		2999	3020	1000	1000

*) RETTET EFTER PRØVEUDTAGNING

		BØR VÆRDI	MÅLT/ BEREG.
TOTAL VAND ....:	L/M3	160.0	159.1
ÆKV.CEMENT ....:	KG/M3	390.4	388.1
ÆKV.V/C ....:		0.41	0.41
SÆTMÅL ....:	mm	120	110
WATTMETER ....:		190.0	124.0
BLANDETID ....:	S	180	182
RUMVÆGT ....:	KG/M3	2301	2330
LUFTINDHOLD I % AF BETON........:	%	5.3	5.9
LUFTPCT I % AF KITMASSE.........:	%	15.1	16.6
TEMPERATUR ....:	oC		18
GENNEMFALD I 0.25 MM SIGTE.....:	%	6	5
GENNEMFALD I 4 MM SIGTE........:	%	33	33
GENNEMFALD I 1/2 D-MAX ....:	%	74	74

BETONKONTROLATTEST UDSKRIFTSDATO: 05.11.96

R455 Vers. 2.4 UDTAGET DEN 05.11.96
KS-FORMULAR 4.10.5.01 NUMMER : 25-5994 SIDE 2

ORDRE :
KUNDE : UNICON BETON RUTH KNUDSEN
KØGEVEJ 172
4000 ROSKILDE

PLADS : GREGERSENSVEJ
DTI PORT 36 2630 TAASTRUP

RECEPT ...: A35BSFAA25DS
STYRKE ...: Fck 35 MPa
V/C PROP : Max
SÆTMÅL ..: 100
KITM.LUFT: Min. 15%
D.MAX ....: Dmax 25 mm
MILJØ KL : Aggressiv
BETONTYPE:

FABRIK.: HEDEHUSENE BL.KL..: 07:47 BL.AF..: OEGE
FLG.SD.: 25-65703 LÆS M3.: 3.00 BIL NR.: 793
UDTAGET: Fabrik UDT.KL.: 08:00 UDT.AF.: PAI

	EMNE.NR	TERM.	MÅLT	BER.
Trykprøvning 7 døgn	25-21	7	kN	MPa
Trykprøvning 28 døgn (1)	25-22	28	kN	MPa
Trykprøvning 28 døgn (2)	25-23	28	kN	MPa
Middelværdi	25-23	28		MPa

APPENDIX 2

Heat Development

DANAK

DTI

Reg. nr.

11

HETEK
Delopgave 3 + 4
Fase 6
DTI Byggeri

Report No.: 5.3458-1
Date: 1996-11-21

BF/jga

Test report

Objective

Determination of heat development in concrete.

Sample

The concrete was delivered by UNICON Beton 1996-11-05.
Concrete mix report: 25-5994
7 samples each containing 5 l were casted by DTI Byggeri.

Test Methods

NT Build 388 (1992). Heat Development.
Haybox calorimeter.

Test Results

The heat development is calculated as kJ/kg cement on page 2, 4, 6, 8, 10, 12 and 14.

The heat development is calculated as kJ/kg cement + mineral additives on page 3, 5, 7, 9, 11, 13 and 15.

Additional information about the concrete and the results are shown on page 16 and 17.

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DTI Byggeri
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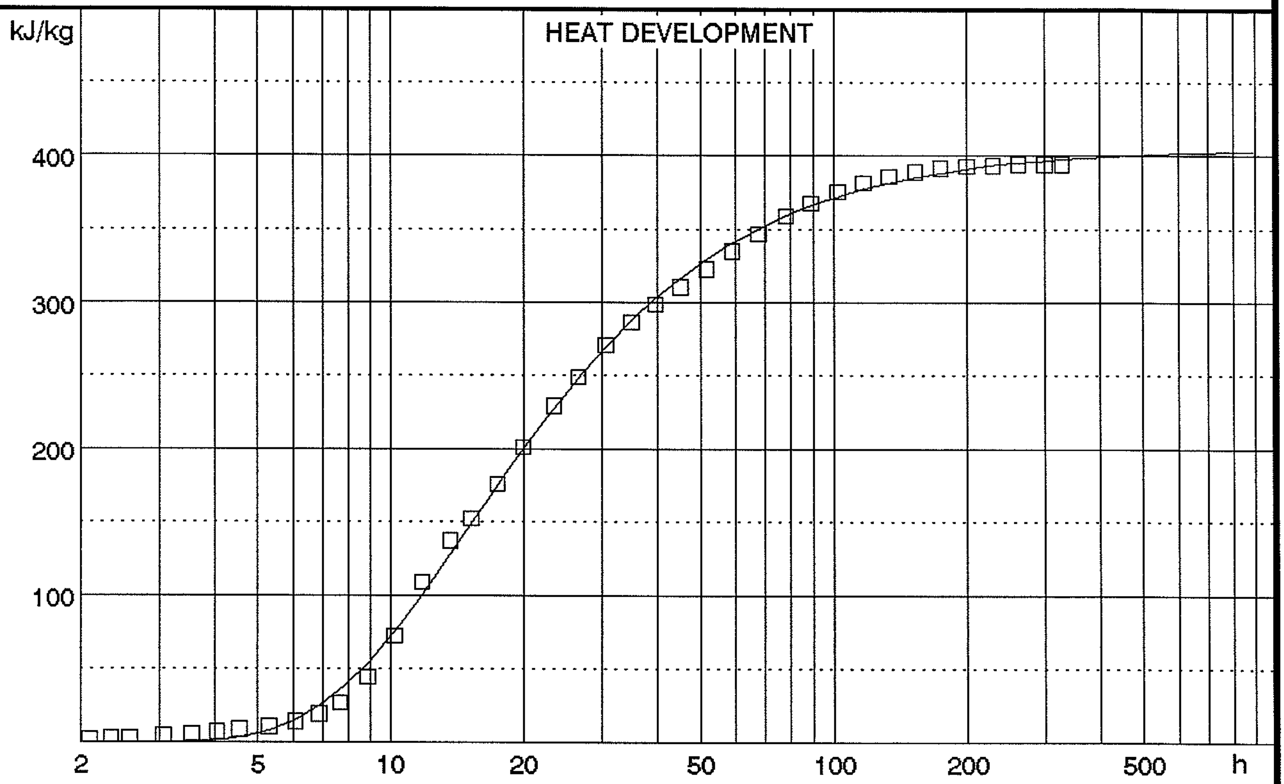
HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB3115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=192.4 kJ/kg To=7.02 h

EXPONENTIAL MODEL
Qinf=405.5 kJ/kg Te=15.24 h Alpha=1.29

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

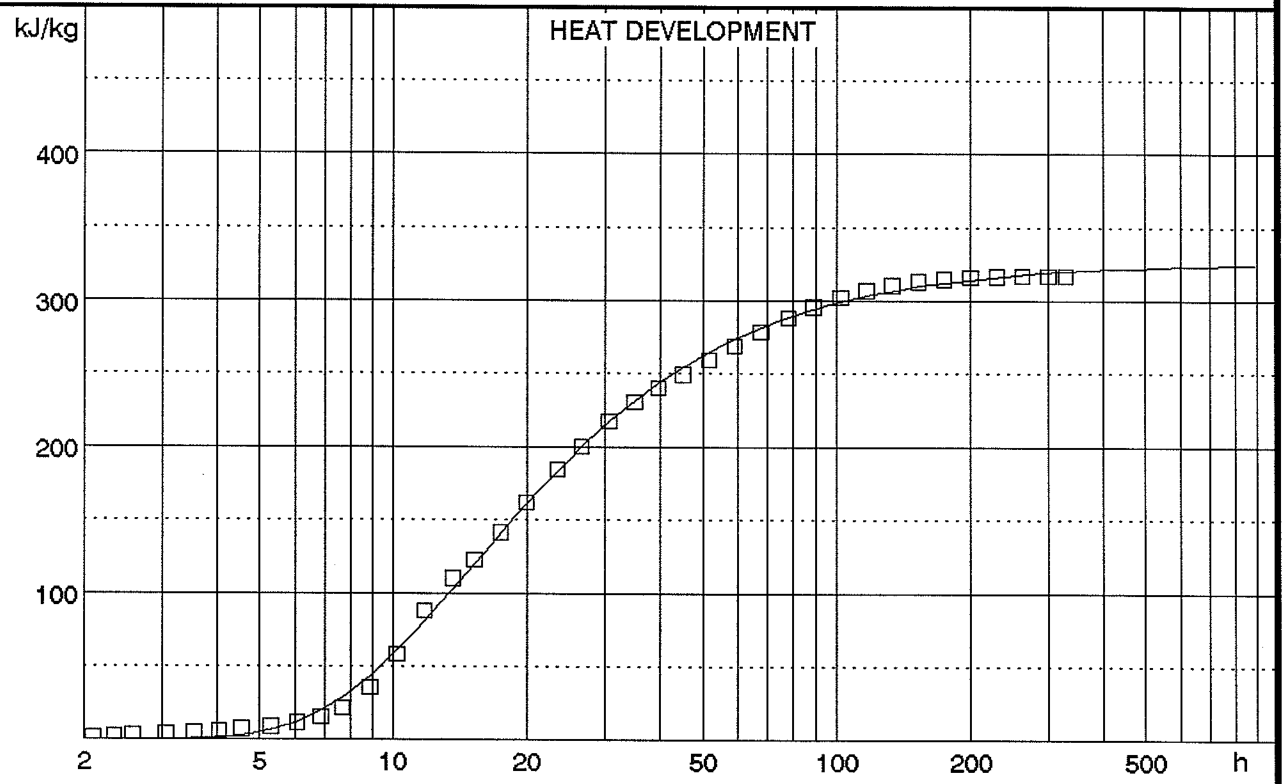
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	1	1.237

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB3115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=154.7 kJ/kg To=7.02 h

EXPONENTIAL MODEL
Qinf=326.2 kJ/kg Te=15.24 h Alpha=1.29

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

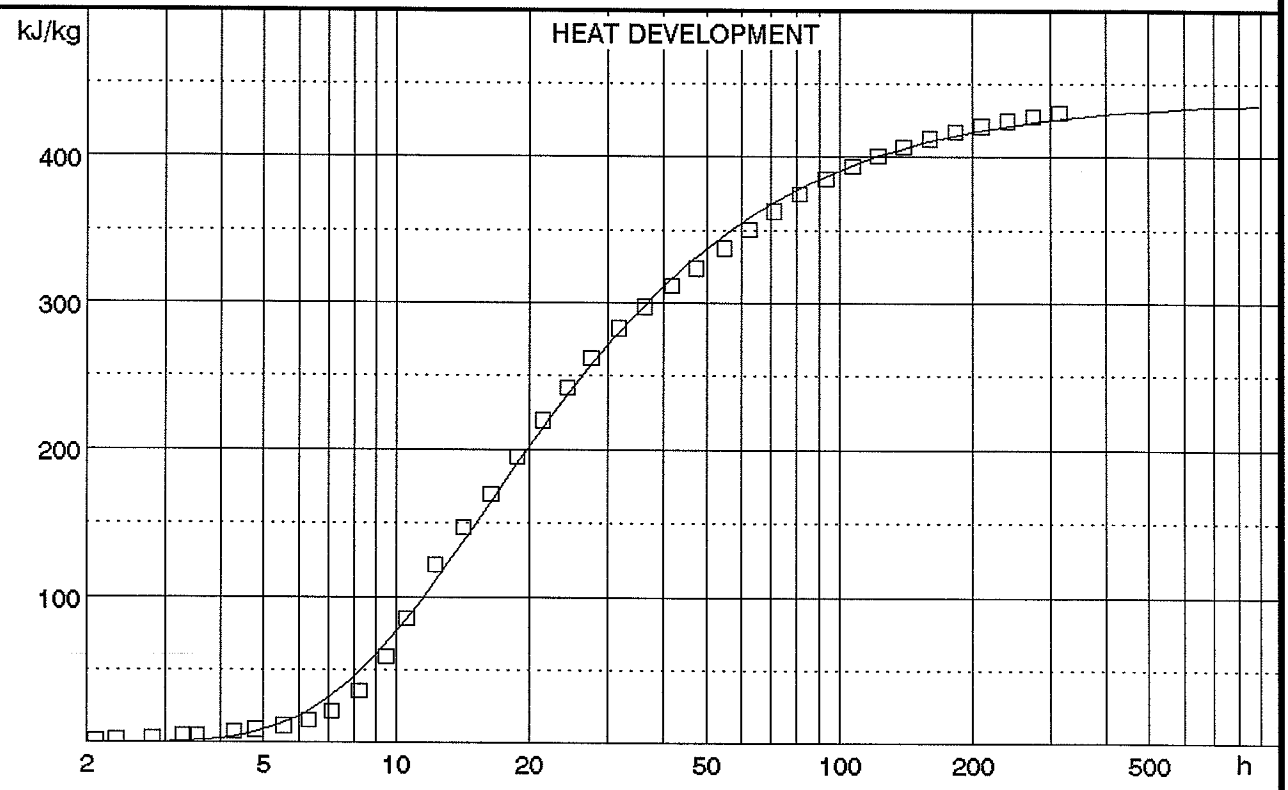
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	1	1.237

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=189.7 kJ/kg To=6.86 h

EXPONENTIAL MODEL
Qinf=439.3 kJ/kg Te=16.09 h Alpha=1.17

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	5	1.229

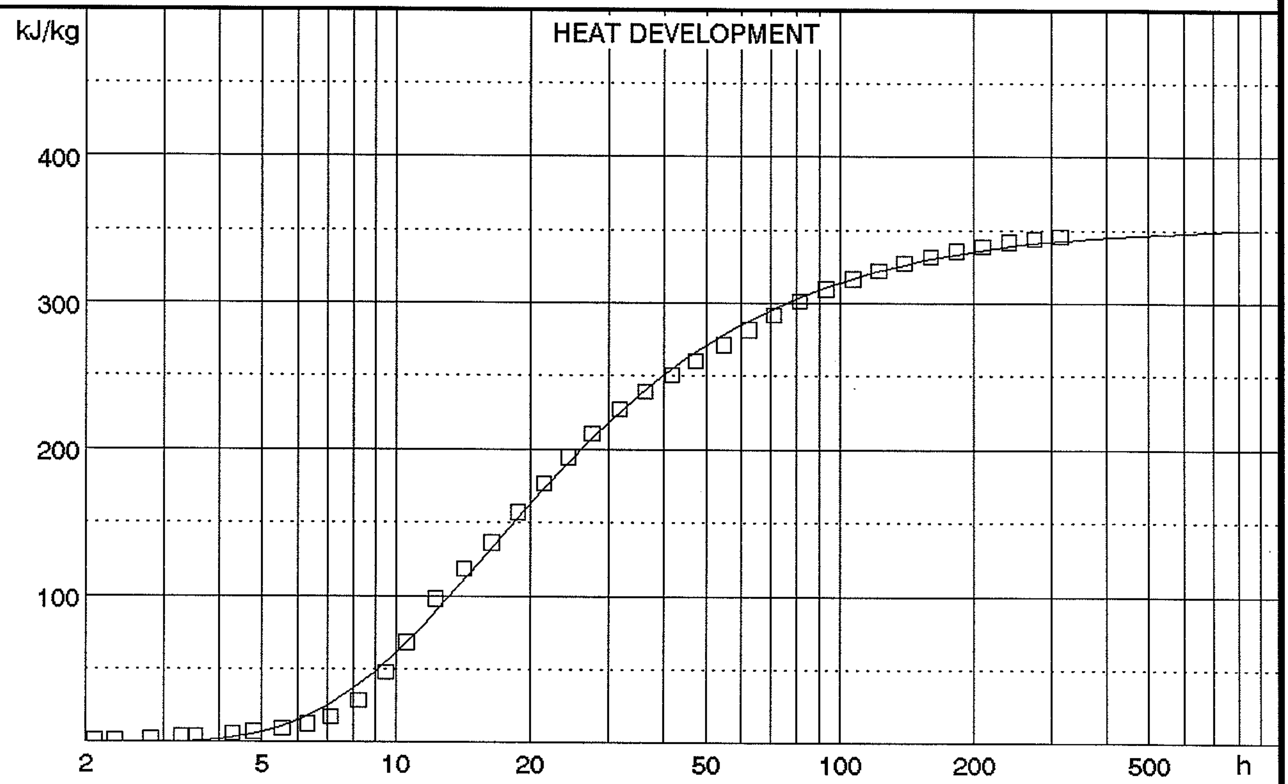
COMMENTS:

DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=152.6 kJ/kg To=6.86 h

EXPONENTIAL MODEL
Qinf=353.4 kJ/kg Te=16.09 h Alpha=1.17

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	5	1.229

COMMENTS:

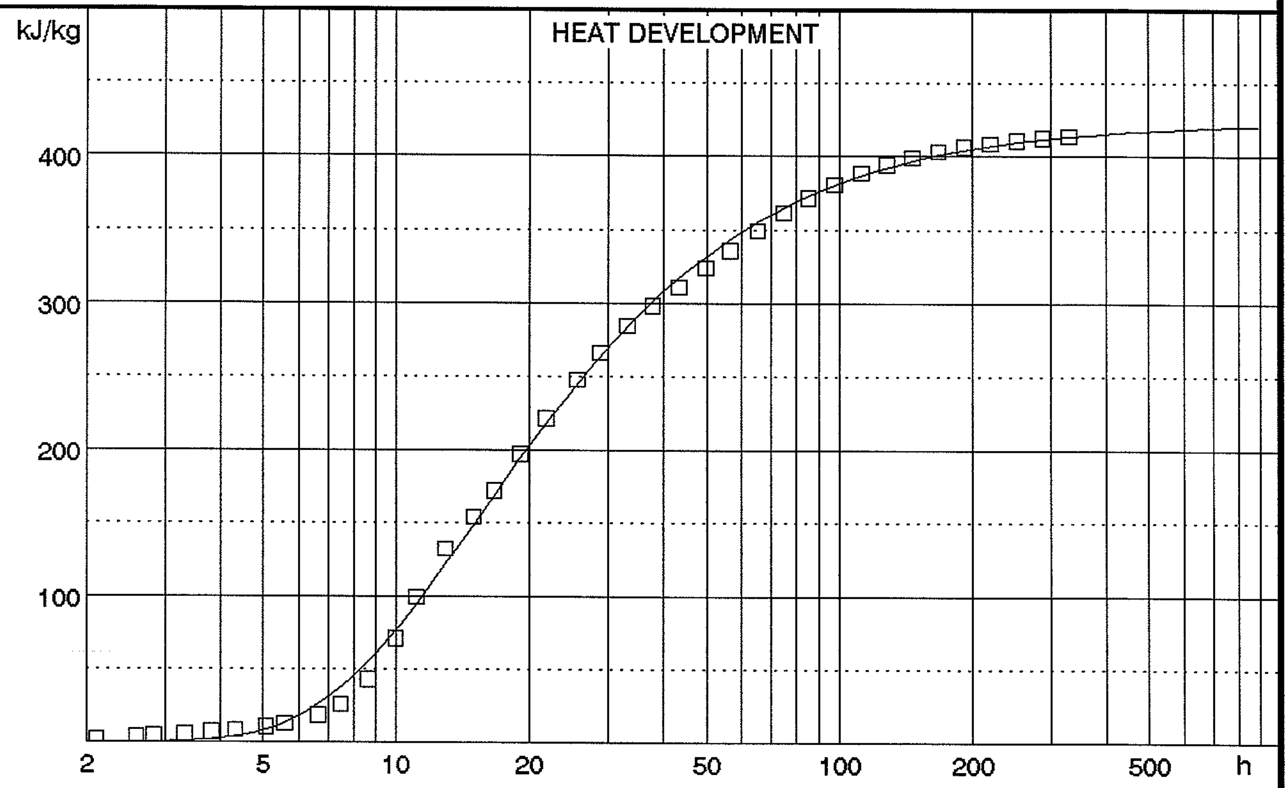
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=188.9 kJ/kg To=6.81 h

EXPONENTIAL MODEL
Qinf=423.7 kJ/kg Te=15.54 h Alpha=1.21

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	6	0.917

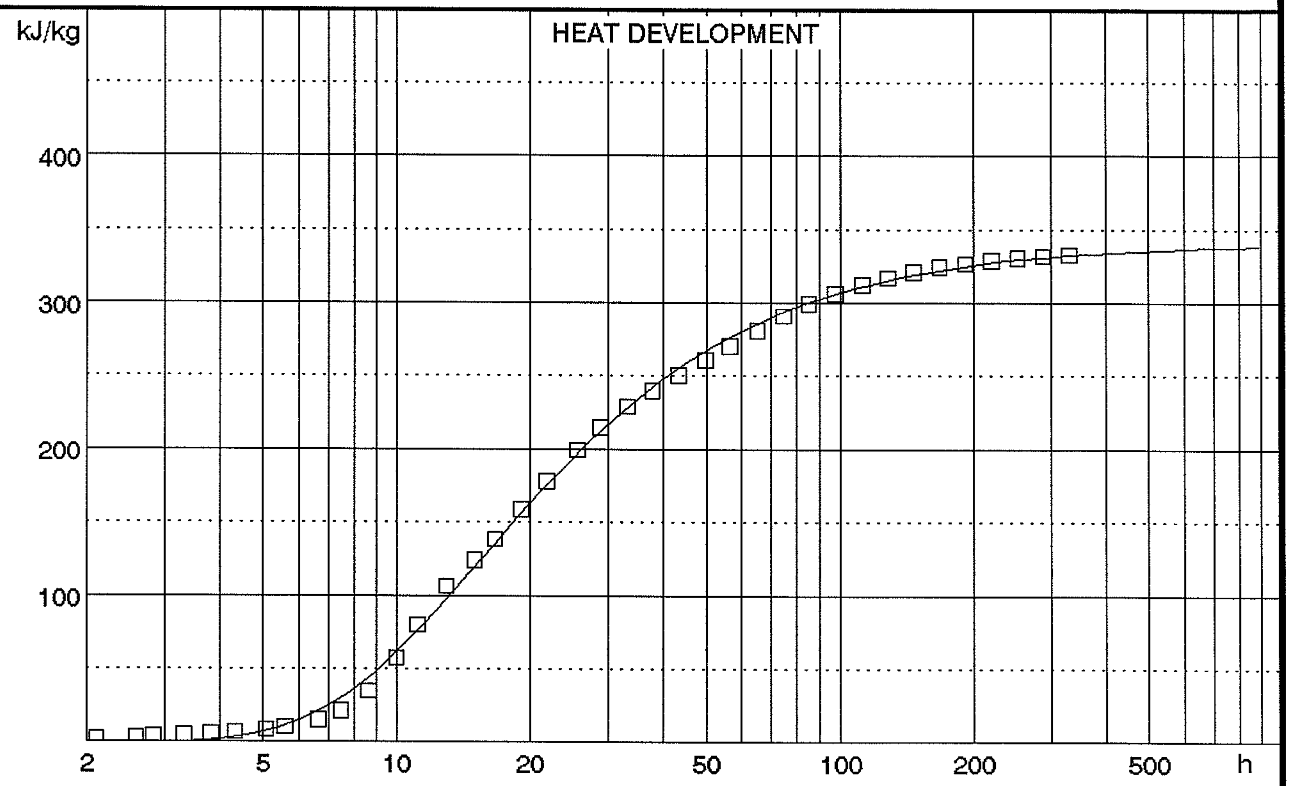
COMMENTS:

DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=152.0 kJ/kg To=6.81 h

EXPONENTIAL MODEL
Qinf=340.8 kJ/kg Te=15.54 h Alpha=1.21

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

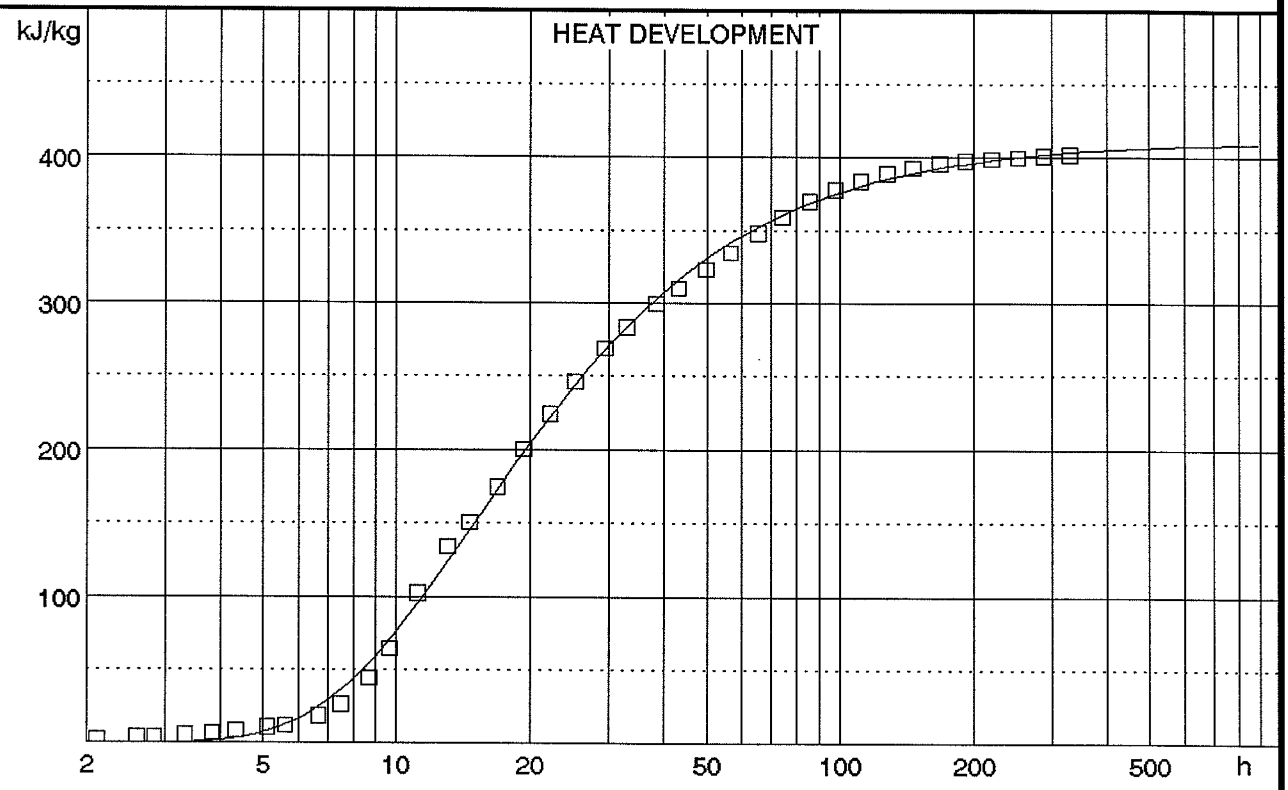
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	6	0.917

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=192.4 kJ/kg To=6.87 h

EXPONENTIAL MODEL
Qinf=411.8 kJ/kg Te=15.10 h Alpha=1.27

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

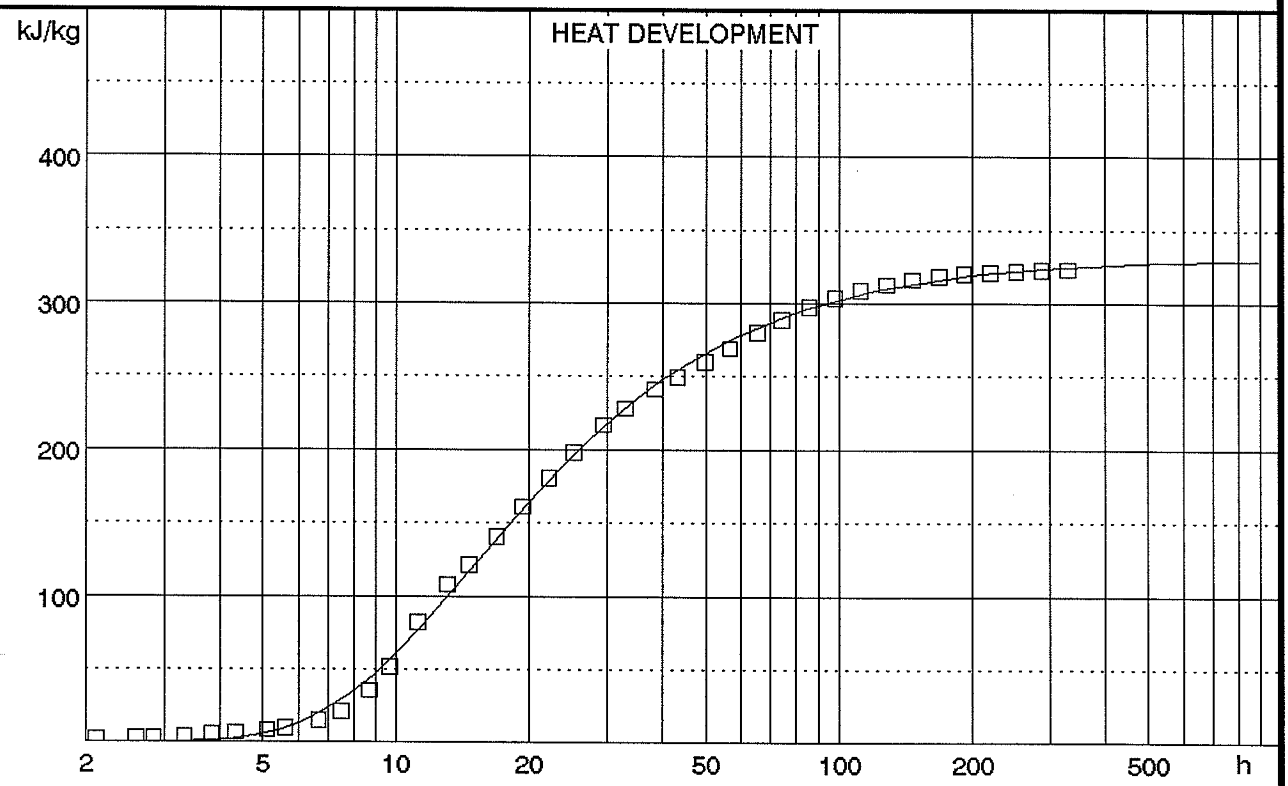
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	7	1.116

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB1115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=154.7 kJ/kg To=6.87 h

EXPONENTIAL MODEL
Qinf=331.2 kJ/kg Te=15.10 h Alpha=1.27

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

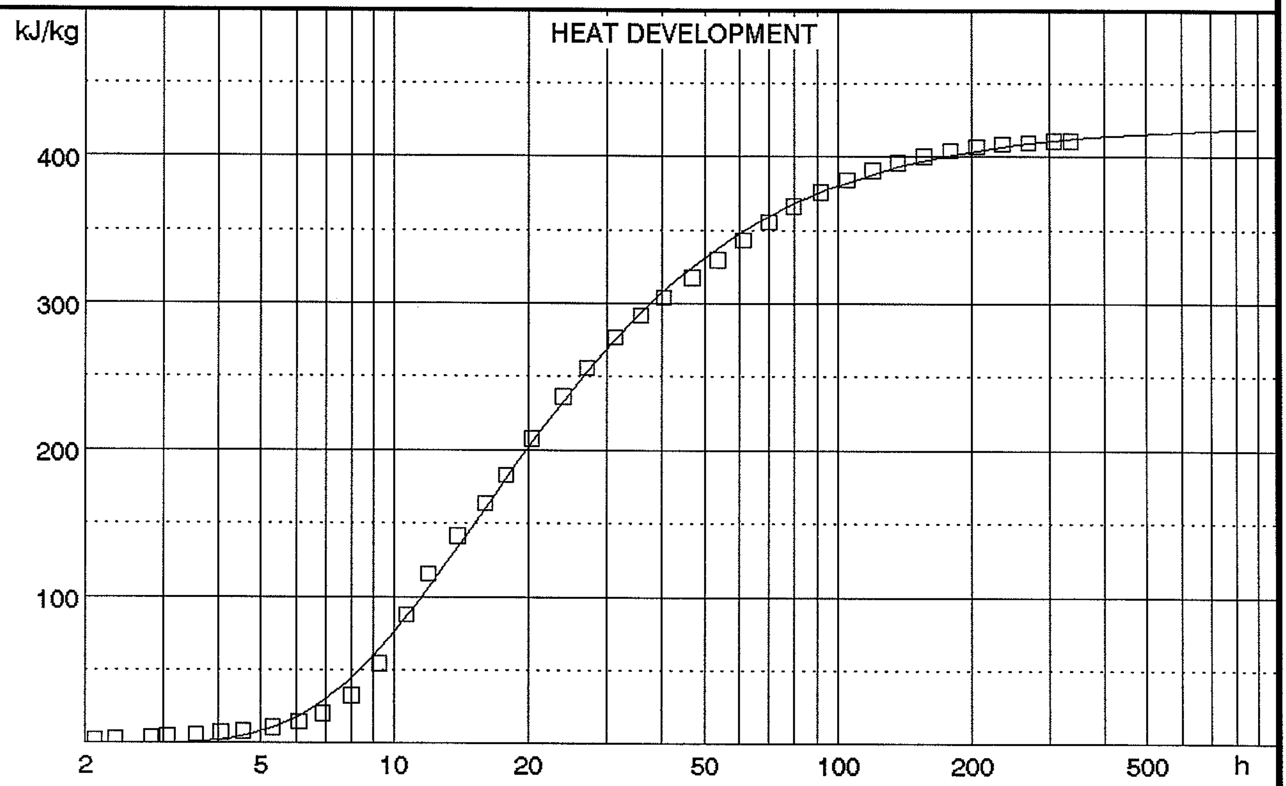
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	7	1.116

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=189.0 kJ/kg To=6.85 h

EXPONENTIAL MODEL
Qinf=422.0 kJ/kg Te=15.56 h Alpha=1.22

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

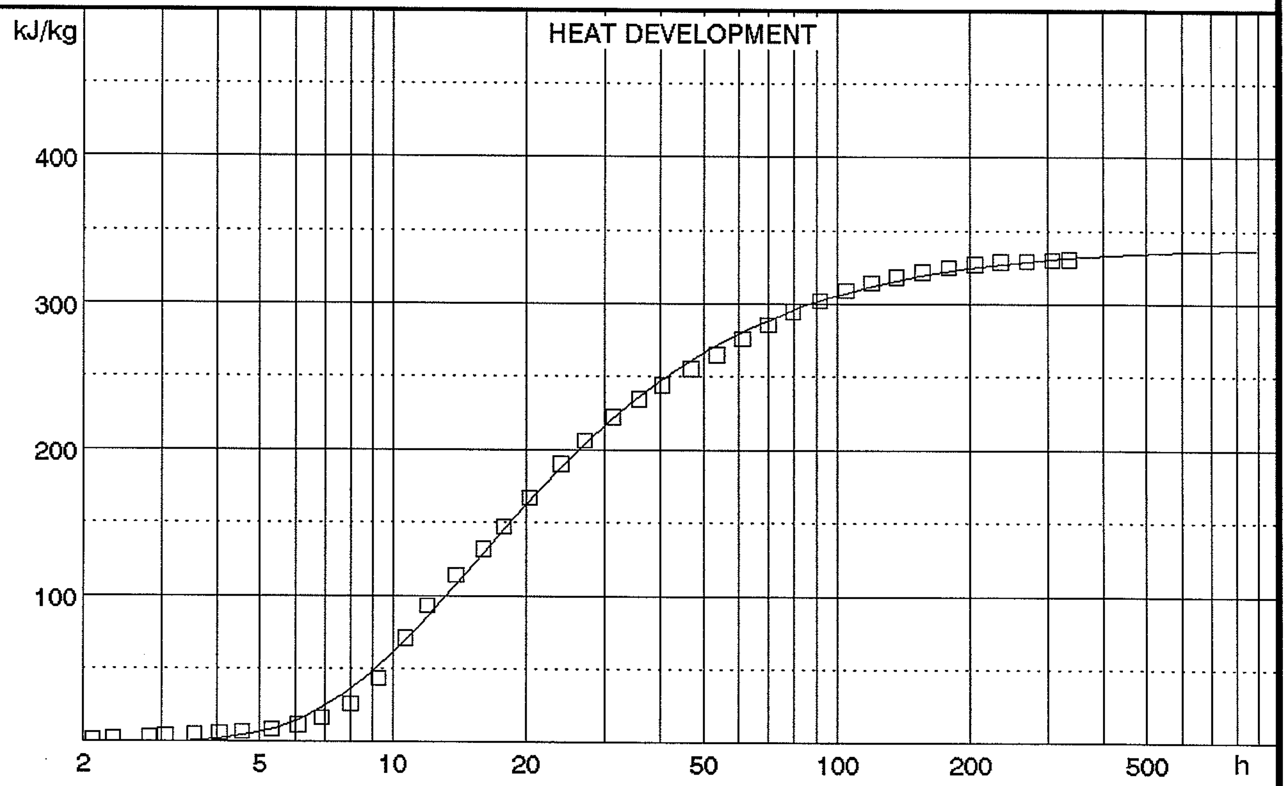
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	10	1.349

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=152.0 kJ/kg To=6.85 h

EXPONENTIAL MODEL
Qinf=339.4 kJ/kg Te=15.56 h Alpha=1.22

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	10	1.349

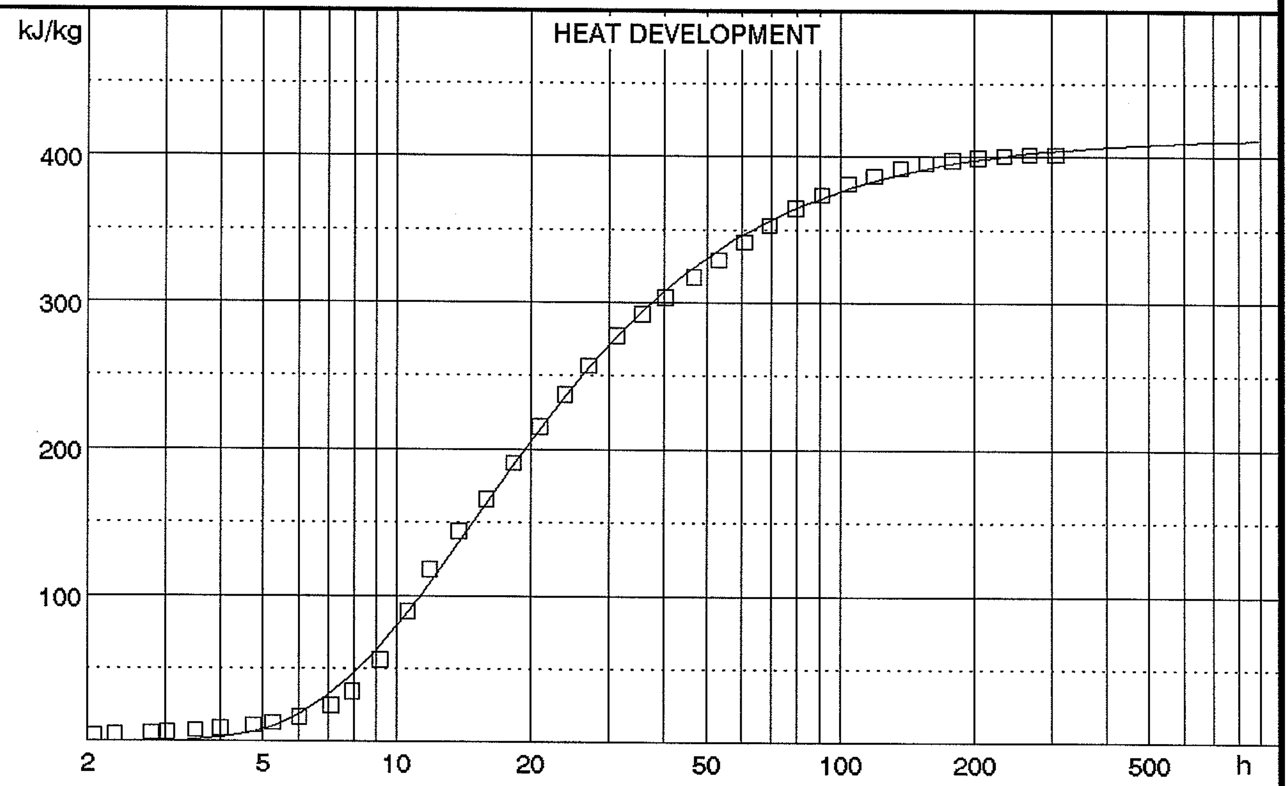
COMMENTS:

DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT
Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=188.9 kJ/kg To=6.70 h

EXPONENTIAL MODEL
Qinf=414.1 kJ/kg Te=15.01 h Alpha=1.24

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

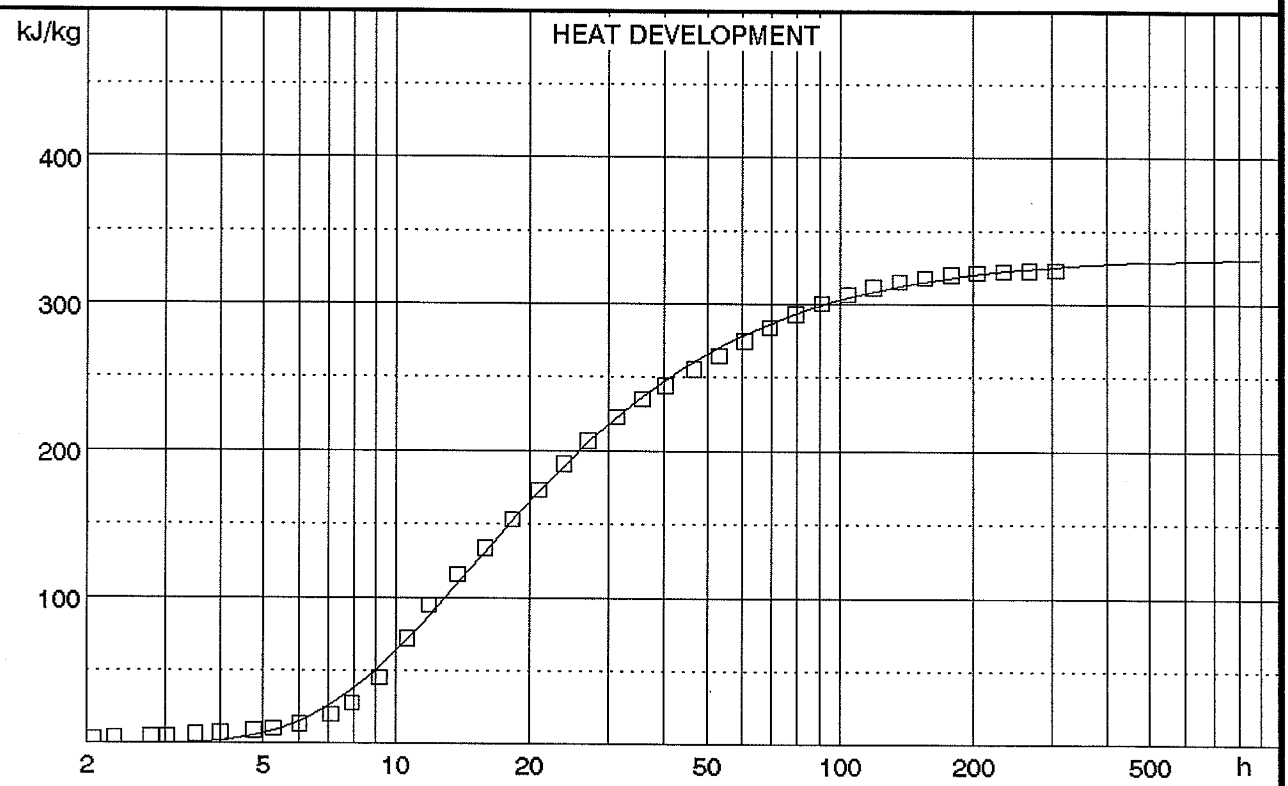
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	15	0.849

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=152.0 kJ/kg To=6.70 h

EXPONENTIAL MODEL
Qinf=333.1 kJ/kg Te=15.01 h Alpha=1.24

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

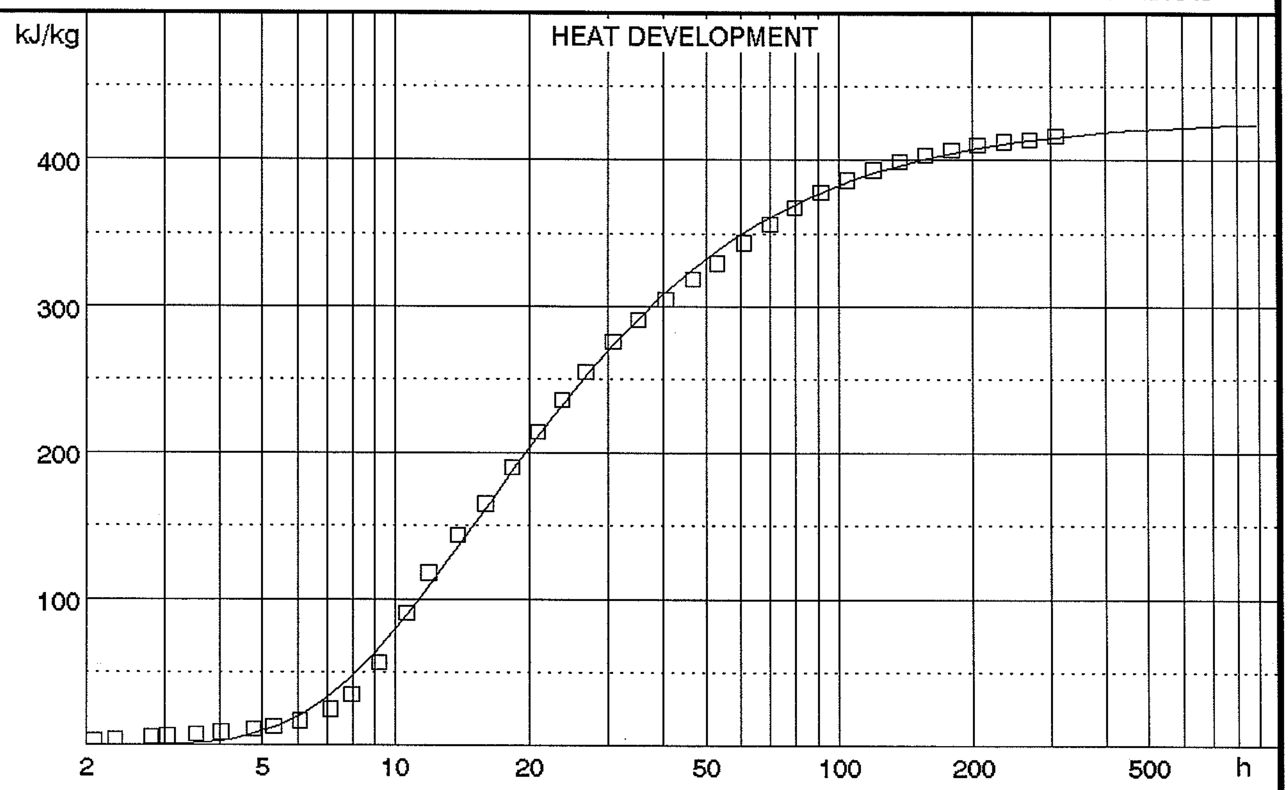
density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	15	0.849

COMMENTS:

DTI Byggeri Gregersensvej, Box 141, 2630 Taastrup	HEAT DEVELOPMENT Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement only Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=185.8 kJ/kg To=6.67 h

EXPONENTIAL MODEL
Qinf=427.9 kJ/kg Te=15.56 h Alpha=1.18

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	18	1.115

COMMENTS:

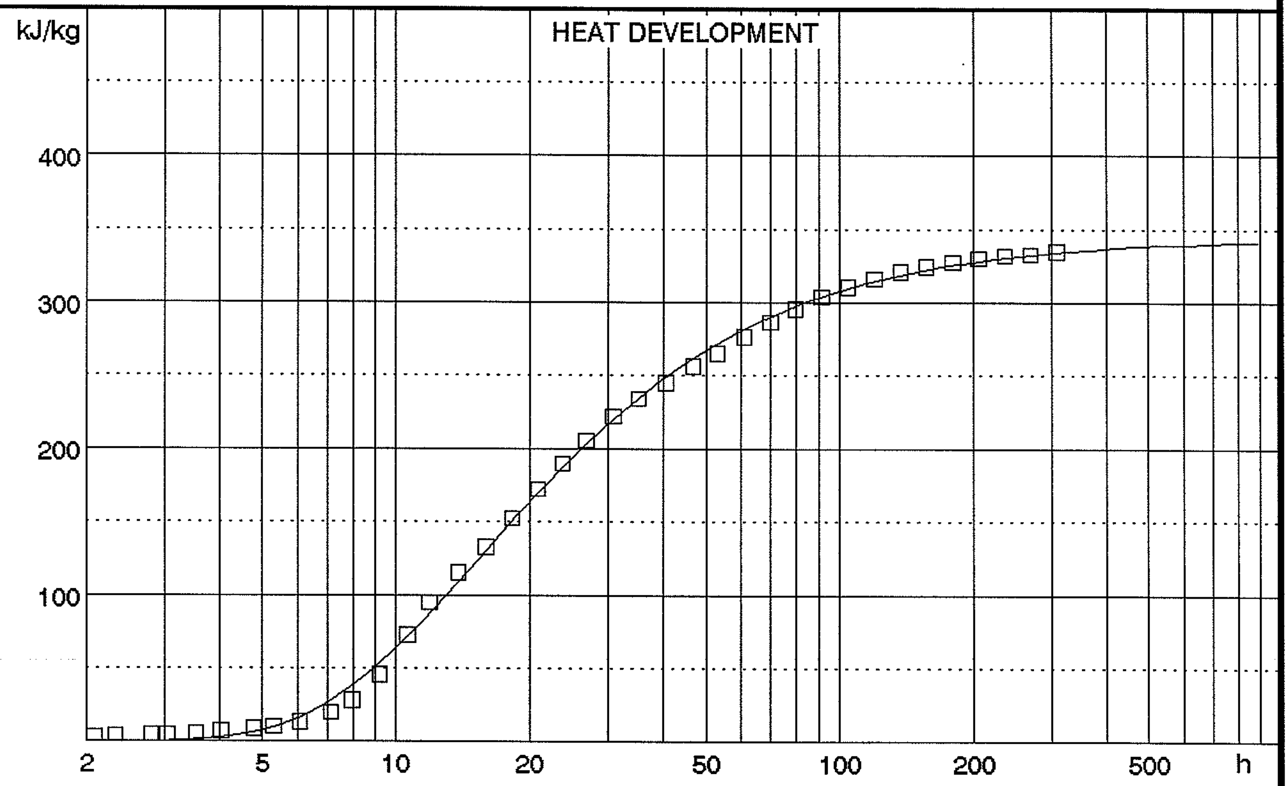
DTI Byggeri
Gregersensvej, Box 141, 2630 Taastrup

HEAT DEVELOPMENT

Documentation sheet

Client: HETEK
Name:

Number: 5.3458 Initials: bf
Date: 21.11.96 Job file: KALHØKAS



DATAFILE: KRYB2115.LOG
CONCRETE: UNICON96-11-05 Cement + min. additives Specific heat: 1.07 kJ/kg/dC

LINEAR MODEL
Qo=149.5 kJ/kg To=6.67 h

EXPONENTIAL MODEL
Qinf=344.2 kJ/kg Te=15.56 h Alpha=1.18

MIX MATERIALS	type	density kg/m3	weight kg/m3	volume m3/m3	comment
Water	VAND	1000.0	155.6	0.156	
Cement	BASIS-CEMENT	3100.0	319.9	0.103	
Mineral additive	FLYVEASKE DAN.	2270.0	58.3	0.026	
	MICROSIL. PULV	2400.0	19.5	0.008	
Aggregate	RN-AVEDø0-4A	2615.0	550.2	0.210	
	DALBY 4-16/A	2750.0	704.9	0.256	
	DALBY 16-25/A	2750.0	487.9	0.177	
Chemical Admixture	SIKAAER-15B	1005.0	1.9	0.002	
	SIKA PLAST-A40	1200.0	2.8	0.002	
Air				0.059	

CONCRETE PROPERTIES

density measured kg/m3	density calculated kg/m3	w/c-ratio kg/kg	air content %	haybox no.	c. factor
2330.0	2301.1	0.41	5.9	18	1.115

COMMENTS:

The concrete mix report states that the composition of the concrete and the material densities are as follows:

Concrete Composition		Density kg/m³
Cement Basis	966,0 kg	3100
Fly ash	176,0 kg	2270
Mikrosilica	59,0 kg	2400
Sand, RN-Avedøre	1661,4 kg**	2615
Stone, Dalby 4-16/A	2128,6 kg**	2750
Stone, Dalby 16-25/A	1473,3 kg**	2750
SikaAer-15B	5,8 kg	1005
Plastiment A40	8,5 kg	1200
Water	469,7 kg*	1000

* The quantity of water does not include the water content of plasticizers and air entrainment.

** The values are stated as values for materials in water saturated surface dry condition.

The concrete mix report states:

Mixing time 1996-11-05, at 07^{47}

Air content:	5,9 %
Density	2330 kg/m³
Slump	110 mm

DTI has determined weight of concrete:

Haybox 1	12,501 kg
Haybox 5	12,666 kg
Haybox 6	12,659 kg
Haybox 7	12,686 kg
Haybox 10	12,768 kg
Haybox 15	12,901 kg
Haybox 18	12,955 kg

The water/cement ratios stated on pages 2 - 15 are the equivalent water/cement ratios calculated as:

water/(cement + 2 x mikrosilica + 0.5 x fly ash).

Table of results:

Test in haybox No.	Q_{inf} [kJ/kg cem.]	Q_{inf} [kJ/kg cem.+min.]	Te [hours]	Alpha
1	405.5	326.2	15.24	1.29
5	439.3	353.4	16.09	1.17
6	423.7	340.8	15.54	1.21
7	411.8	331.2	15.10	1.27
10	422.0	339.4	15.56	1.22
15	414.1	333.1	15.01	1.24
18	427.9	344.2	15.56	1.18
Average	420.6	338.3	15.44	1.23
Duration	11.3	9.1	0.37	0.04

APPENDIX 3

Thermal Expansion Coefficient

HETEK
Subtask 3 + 4
Stage 6
DTI Byggeri

Test report

Objektive Determination of Thermal Expansion Coefficient.

Client	:	HETEK
Sampler	:	The specimens were cast by DTI with concrete delivered by Unicon, Hedehusene
Delivery note:		Delivery note no. 25-65703

Specimens

Type	:	casted concrete prisms 100x100x400 mm.
Designation	:	A35BSFAA25DS
Casting	:	1996-11-05

Test Methods TI-B 101 (September 1994) : Test Method. Concrete. Thermal Expansion Coefficient.

Test Results The results of the tests are shown at page 2.

The heating from 5°C to 30°C lasted between 2,2 and 3,8 h. In this relative short period no measurable shrinkage was detected.

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Thermal expansion coeff. according to TI-B 101

Date of Casting: 1996-11-05

Date of testing: 1996-11-06 Maturity: app. 1 day

Specimen Mark	alfa 1/°C
1 2 3	1,00E-5 0,97E-5
Mean St. dev.	0,98E-5

Spec. no 3 got wet and has been left out for the rest of the test.

Date of testing: 1996-11-08 Maturity: app. 3 day

Specimen Mark	alfa 1/°C
1 2 3	1,05E-5
Mean St. dev.	1,05E-5

Spec. no 2 got wet and has been left out for the rest of the test.

Date of testing: 1996-11-12 Maturity: app. 7 day

Specimen Mark	alfa 1/°C
1 2 3	1,06E-5
Mean St. dev.	1,06E-5

Mean of all measurings: 1,02E-5 1/°C

APPENDIX 4

E-modulus and Compressive Strength Developments

HETEK
Subtask 3 + 4
Stage 6
DTI Byggeri

Report no. : 53458-3
Date : 1996-12-06

Appendix : 1

Test report

Objektive Determination of E-modulus and compressive strength developments.

Client : HETEK
Sampler : The specimens were cast by DTI with concrete delivered by Unicon.
Delivery note: Delivery note no. 25-65703

Specimens

Type : casted concrete cylinders D150 x H300 mm
Designation : A35BSFAA25DS
Casting : 1996-11-05

The maturity of the specimens was estimated to be 29,0h at 1996-11-05 - 9:35.

Test Methods DS 423.23 (March 1984): Testing of Concrete - Hardened Concrete - Compressive Strength

DS 423.25 (March 1984): Testing of Concrete - Hardened Concrete - Modulus of Elasticity

The tests departs from the methods at early ages (1/2, 1, 2 and 3 days), as the loadrate used was 0.2 MPa/s. For testing of E-modulus at 1/2 day all load levels were 45% of comp. strength.

Test Results The results of the tests are shown at page 2-10. E-modulus and compressive strength developments are shown in appendix 1.

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E-modulus according to DS 423.25 - Main Results

Time	Specimen	Maturity hours	E0 MPa	Ec MPa
0	4 20 24	12,3 12,5 12,1	12400 13000 10900	12700 13000 10800
mean		12,3	12100	12200
1	2 6 28	29,7 29,3 29,1	27900 27800 29400	28300 28400 28500
mean		29,4	28400	28400
2	11 41 42	53,4 53,6 53,9	29600 31300 31400	29400 30600 30200
mean		53,6	30800	30100
3	15 47 50	78,0 77,7 77,5	32200 32700 32100	31900 32000 31100
mean		77,7	32300	31700
7	12 30 38	175,8 174,3 174,1	34400 36300 35100	33800 35800 34100
mean		174,7	35300	34600
14	9 23 44	342,1 341,6 341,8	38200 37500 38400	37300 37500 38000
mean		341,8	38000	37600
28	1 14 22	678,0 678,3 677,4	37700 38100 38800	37000 38200 38600
mean		677,9	38200	37900

Compressive Strength according to DS 423.23 - Main Results

Time	Specimen	Maturity hours	Comp. strength MPa
0	37	11,5	3,3
	4 20 24	12,3 12,5 12,1	4,7 5,5 4,7
1	34	28,8	23,0
	2 6 28	29,7 29,3 29,1	24,6 22,4 23,3
2	49	53,2	35,9
	11 41 42	53,4 53,6 53,9	32,3 35,2 32,0
3	39	77,3	38,1
	15 47 50	78,0 77,7 77,5	33,7 35,9 37,1
7	16	173,7	44,6
	12 30 38	175,8 174,3 174,1	43,3 44,7 46,2
14	36	341,2	49,1
	9 23 44	342,1 341,6 341,8	50,9 53,3 51,5
28	27	677,0	52,7
	1 14 22	678,0 678,3 677,4	52,6 55,4 57,4

Report no. : 53458-3
Date : 1996-12-06

Appendix : 1

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-05

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
4	12,3	149,9	300,5	2381	12400	12700	4,7
20	12,5	151,2	298,6	2364	13000	13000	5,5
24	12,1	150,6	300,4	2387	10900	10800	4,7
Mean				2377	12100	12200	5,0
Standard deviation							

If the specimen was recentered E0 is not determined.
The compressive strength departs more than 20% from the presumed.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
37	11,5	149,8	300,2	2399	3,3

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-06

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
2	29,7	150,0	300,9	2413	27900	28300	24,6
6	29,3	150,8	300,6	2388	27800	28400	22,4
28	29,1	149,9	300,0	2408	29400	28500	23,3
Mean Standard deviation				2403	28400	28400	23,4

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
34	28,8	150,8	300,4	2389	23,0

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-07

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
11	53,4	150,4	300,4	2399	29600	29400	32,3
41	53,6	149,9	300,3	2400	31300	30600	35,2
42	53,9	149,6	300,0	2410	31400	30200	32,0
Mean Standard deviation				2403	30800	30100	33,2

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
49	53,2	149,8	300,2	2405	35,9

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-08

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
15	78,0	149,8	300,7	2413	32200	31900	33,7
47	77,7	149,9	300,2	2396	32700	32000	35,9
50	77,5	149,8	300,5	2402	32100	31100	37,1
Mean				2404	32300	31700	35,6
Standard deviation							

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
39	77,3	150,4	300,4	2410	38,1

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-12

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
12	175,8	150,4	300,4	2413	34400	33800	43,3
30	174,3	150,4	300,4	2416	36300	35800	44,7
38	174,1	150,0	300,6	2406	35100	34100	46,2
Mean Standard deviation				2412	35300	34600	44,8

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
16	173,7	151,3	299,9	2405	44,6

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-11-19

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
9	342,1	150,7	300,3	2404	38200	37300	50,9
23	341,6	149,9	300,0	2409	37500	37500	53,3
44	341,8	150,1	300,3	2394	38400	38000	51,5
Mean Standard deviation				2402	38000	37600	51,9

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
36	341,2	150,2	300,6	2429	49,1

E-modulus according to DS 423.25

Date of casting: 1996-11-05
Date of testing: 1996-12-03

Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Densi-ty kg/m³	E0 MPa	Ec MPa	Comp. strength MPa
1	678,0	150,4	300,4	2409	37700	37000	52,6
14	678,3	150,1	300,1	2404	38100	38200	55,4
22	677,4	150,0	300,2	2434	38800	38600	57,4
Mean				2416	38200	37900	55,1
Standard deviation							

If the specimen was recentered E0 is not determined.

Compressive strength determined just before determination of the E-modulus:

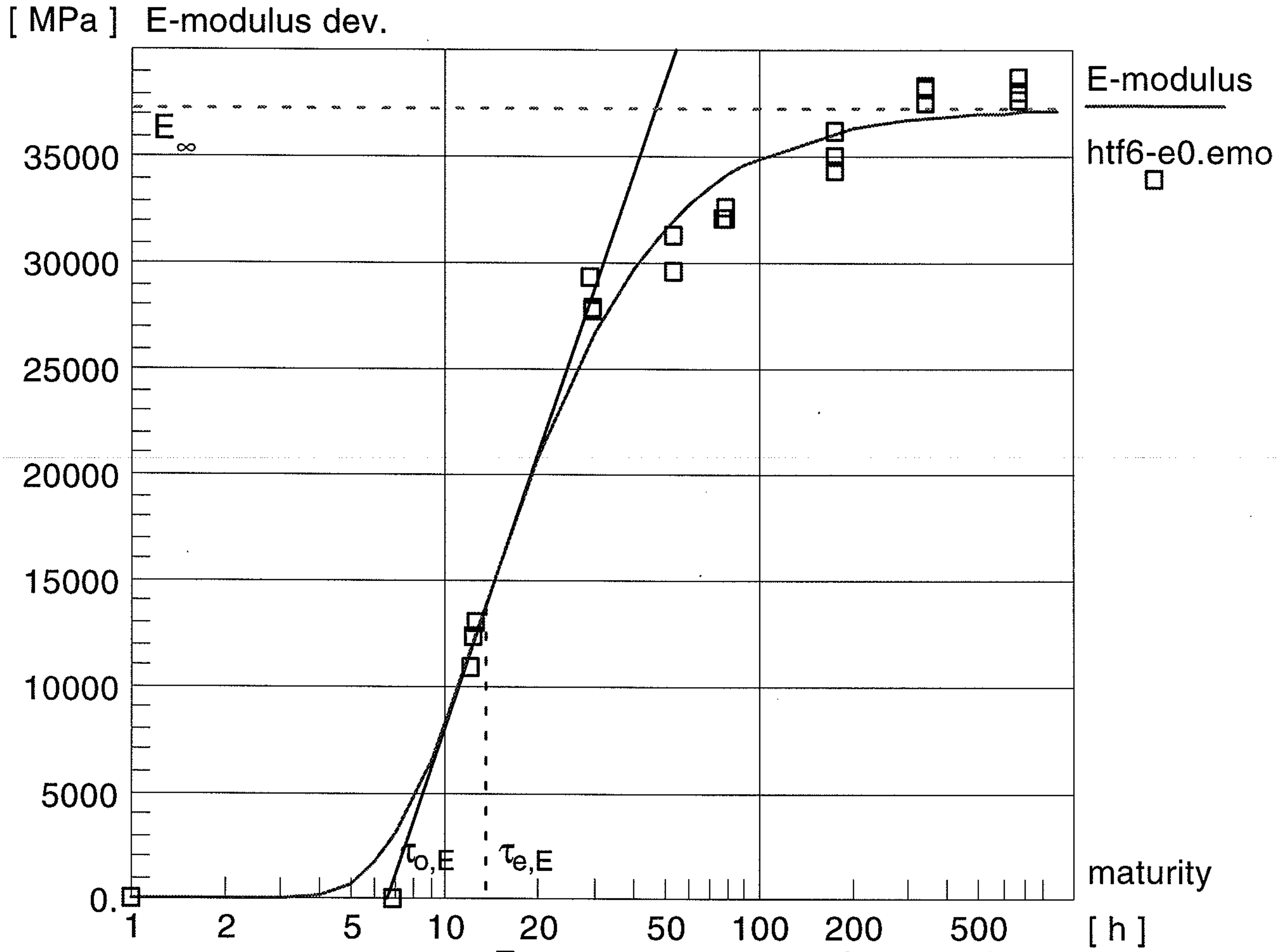
Spec. Mark	Maturity hours	Dia-meter mm	Height mm	Density kg/m³	Comp.strength MPa
27	677,0	150,0	300,4	2410	52,7

DTI Building Technology	CALCULATION BASIS
Gregersensvej, DK 2630 Taastrup	Documentation sheet

Client: HETEK 3 + 4	Ref. nr.: 534534	Project: esp6	Date: 12/09/96
Name: Stage 1	Initials : HSP	Id. nr. : VE-AA0980	Time: 10:15

Concrete database — Hetek fase6

E-modulus development



Linear Model: $E_1 = 18913.89$ $\tau_{o,E} = 6.53$ $E_o = 0.$

Exponential Model: $E_\infty = 37256.$ $\tau_{e,E} = 13.48$ $\alpha_E = 1.38$ $E_o = 0.$

Exponential Model:

$E = E_o - (E_o - E_\infty) * EXP(-(\tau_{e,E} / M)^{\alpha_E})$

E_∞ : Total

$\tau_{e,E}$: Time

α_E : Cuverture

M : Maturity time

E_o : Start/Fresh

Linear Model:

$E = E_o - (E_o - E_1) * LN(M / \tau_{o,E})$

E_1 : Ordinate for $\tau_{e,E}$

$\tau_{o,E}$: Intersection with axis of maturity

M : Maturity time

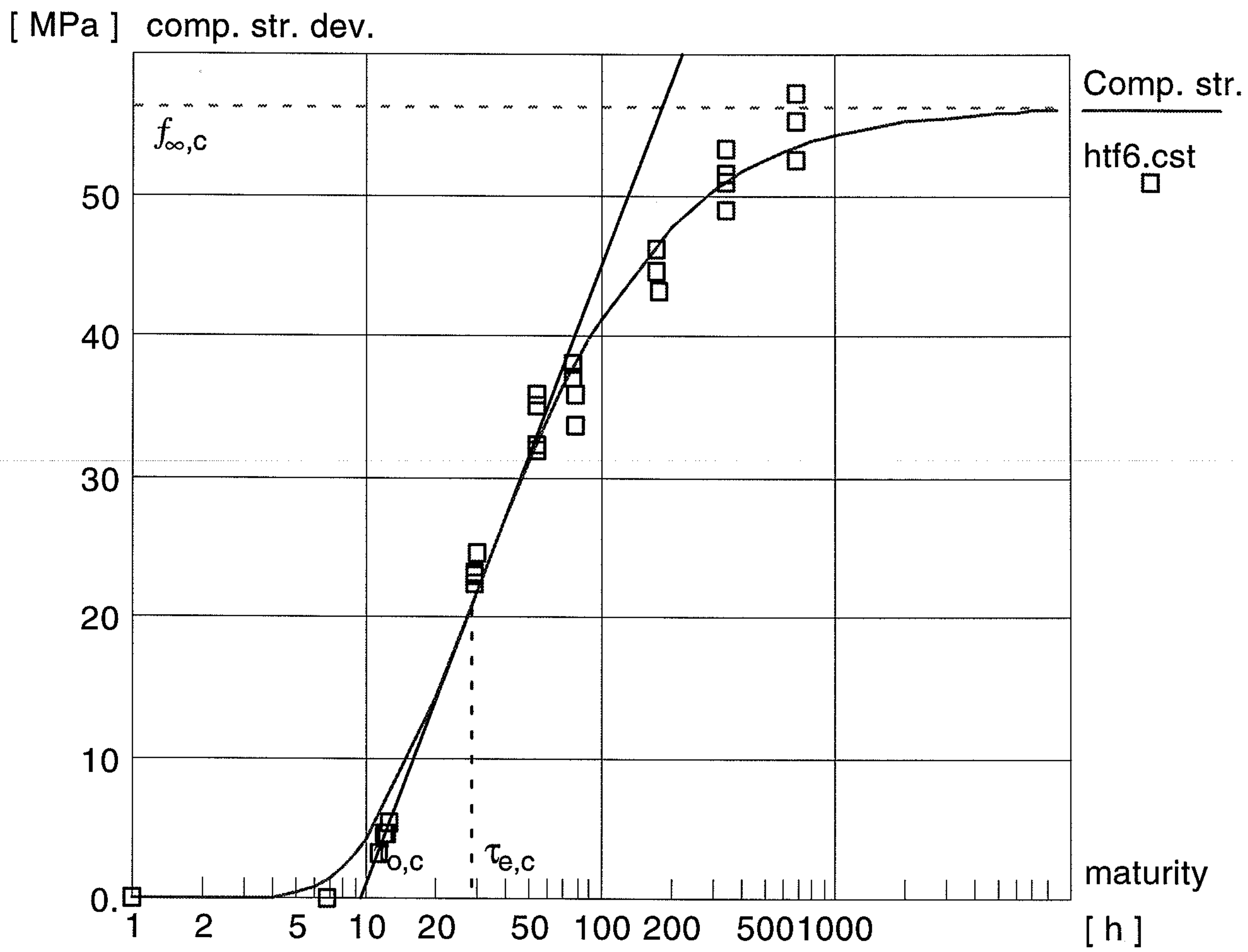
E_o : Start/Fresh

DTI Building Technology Gregersensvej, DK 2630 Taastrup	CALCULATION BASIS Documentation sheet

Client: HETEK 3 + 4	Ref. nr.: 534534	Project: esp6	Date: 12/09/96
Name: Stage 1	Initials : HSP	Id. nr. : VE-AA0980	Time: 10:18

Concrete database — Hetek fase6

Compressive strength development



Linear Model: f_1 = 19.09 $\tau_{o,c}$ = 9.51 f_o = 0.
Exponential Model: $f_{\infty,c}$= 56.4 $\tau_{e,c}$ = 28.19 α_c = 0.92 f_o = 0.

Exponential Model:

$$f = f_o - (f_o - f_{\infty,c})^{*}EXP(-(\tau_{e,c}/M)^{\alpha_c})$$

$f_{\infty,c}$: Total
$\tau_{e,c}$: Time
α_c : Cuverture
M : Maturity time
f_o : Start/Fresh

Linear Model:

$$f = f_o - (f_o - f_1)^{*}LN(M/\tau_{o,c})$$

f_1 : Ordinate for $\tau_{e,c}$
$\tau_{o,c}$: Intersection with axis of maturity
M : Maturity time
f_o : Start/Fresh

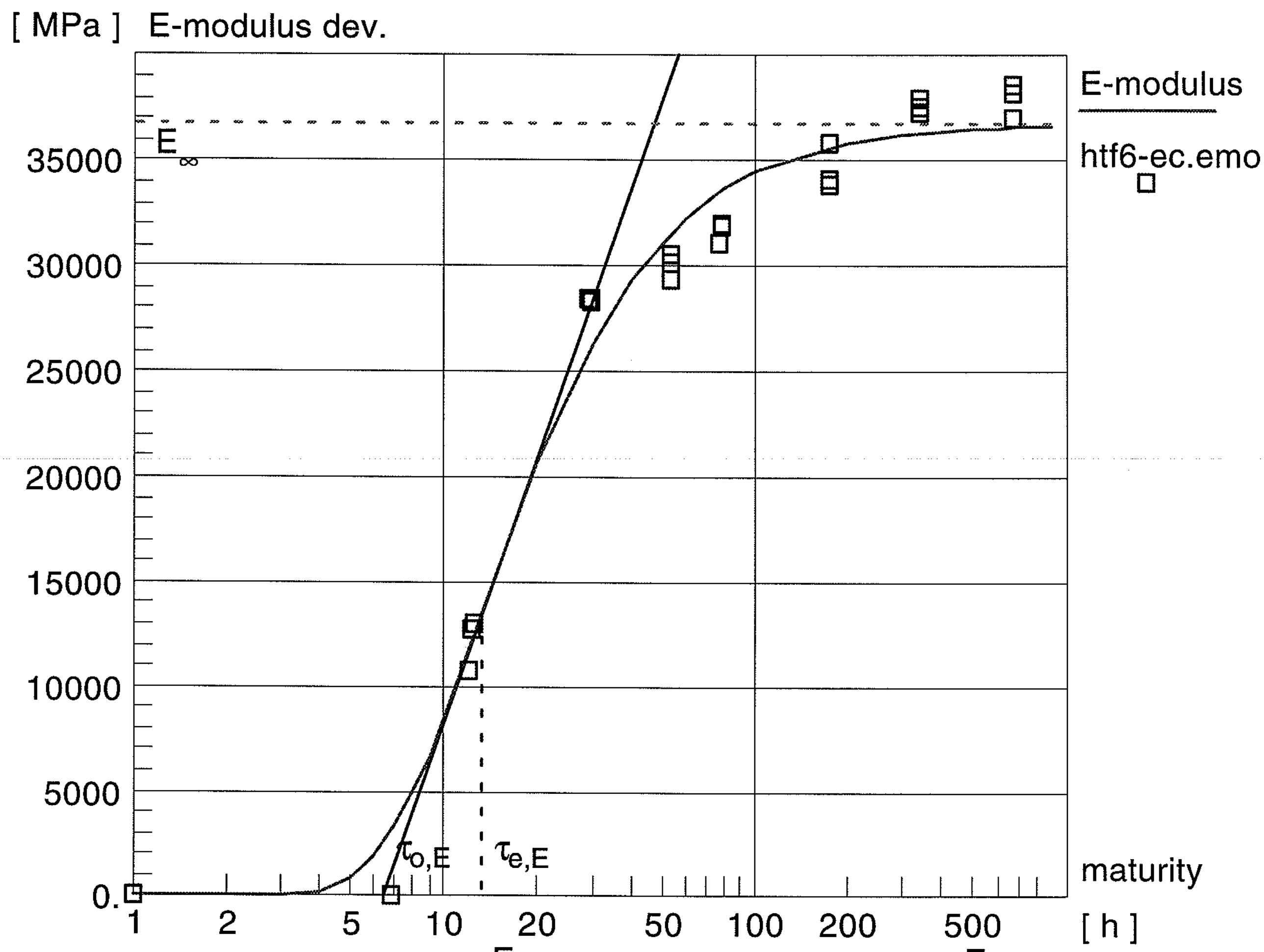
DTI Building Technology Gregersensvej, DK 2630 Taastrup	CALCULATION BASIS Documentation sheet

Client: HETEK 3 + 4	Ref. nr.: 534534	Project: esp6	Date: 12/09/96
Name: Stage 1	Initials : HSP	Id. nr. : VE-AA0980	Time: 10:16

Concrete database

Hetek fase6

E-modulus development



Linear Model: $E_1 = 18386.01$ $\tau_{o,E} = 6.38$ $E_o = 0.$

Exponential Model: $E_\infty = 36748.8$ $\tau_{e,E} = 13.31$ $\alpha_E = 1.36$ $E_o = 0.$

Exponential Model:

$E = E_o - (E_o - E_\infty) * EXP(-(\tau_{e,E} / M)^{\alpha_E})$

E_∞ : Total

$\tau_{e,E}$: Time

α_E : Cuverture

M : Maturity time

E_o : Start/Fresh

Linear Model:

$E = E_o - (E_o - E_1) * LN(M/\tau_{o,E})$

E_1 : Ordinate for $\tau_{e,E}$

$\tau_{o,E}$: Intersection with axis of maturity

M : Maturity time

E_o : Start/Fresh

APPENDIX 5

Splitting Tensile Strength Development

DANAK

Reg. nr. 11

DTI

HETEK
Subtask 3 + 4
Stage 6
DTI Byggeri

Report no.	:	53458-4
Date	:	1997-01-02
Page	:	1 of 9
Appendix	:	1

Test report

Objektive

Determination of splitting tensile strength development.

Client	:	HETEK
Sampler	:	The specimens were cast by DTI with concrete delivered by Unicon,
Delivery note	:	Delivery note no. 25-65703

Specimens

Type	:	Casted concrete cylinders D150 x H300 mm
Designation	:	A35BSFAA25DS
Casting	:	1996-11-05

The maturity of the specimens was estimated to be 29,0 h at 96-11-05 - 9:35.

Test Method bestemmelser

DS 423.34 (January 1985): Testing of Concrete - Tensile strength deduced from splitting test on cylindrical specimens.

The tests departs from the methods at early ages (1/2, 1, 2 and 3 days), as the load rate used was 0.018 MPa/s.

Test Results

The results of the tests are shown at page 2-9 . The splitting tensile strength development is shown in appendix 1.

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Splitting Tensile Strength according to DS 423.34 - Main Results

Time days	Specimen	Maturity (hours)	Split. tens. strength (MPa)
0	26 29 45	12,4 12,5 12,6	0,61 0,67 0,66
mean		12,5	0,65
1	5 19 21	30,0 30,1 29,9	2,21 2,14 2,27
mean		30,0	2,21
2	31 46 48	54,1 54,2 54,2	2,86 2,81 3,03
mean		54,2	2,90
3	3 13 18	78,5 78,7 78,6	3,02 2,59 2,86
mean		78,6	2,82
7	8 17 40	175,6 175,7 175,8	3,40 3,51 3,92
mean		175,7	3,61
14	7 10 25	342,3 342,4 342,2	3,82 3,46 3,58
mean		342,3	3,62
28	32 33 35	678,0 678,0 678,0	3,58 4,45 4,48
mean		678,0	4,17

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-05

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
26	12,4	150,7	300,5	2402	43,7	0,61
29	12,5	150,6	300,0	2397	47,3	0,67
45	12,6	150,5	300,2	2403	47,0	0,66
Mean				2401	46,0	0,65
Standard deviation				3	2,0	0,03

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-06

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
5	30,0	150,2	300,0	2394	156,5	2,21
19	30,1	150,1	300,2	2403	151,5	2,14
21	29,9	150,7	300,0	2393	161,4	2,27
Mean				2397	156,5	2,21
Standard deviation				6	5,0	0,07

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-07

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
31	54,1	150,9	300,4	2388	203,6	2,86
46	54,2	149,9	300,6	2390	199,1	2,81
48	54,2	149,6	300,5	2408	214,0	3,03
Mean				2395	205,6	2,90
Standard deviation				11	7,6	0,12

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-08

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
3	78,5	149,9	300,0	2412	213,1	3,02
13	78,7	150,6	300,4	2408	184,2	2,59
18	78,6	151,1	299,0	2411	203,1	2,86
Mean				2410	200,1	2,82
Standard deviation				2	14,7	0,22

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-12

Spec. Mark	Maturity hours	Diameter mm	Heigth mm	Density kg/m³	Fail. load kN	Split. tens. strength MPa
8	175,6	150,2	300,1	2407	241,0	3,40
17	175,7	149,0	300,4	2404	246,5	3,51
40	175,8	149,5	300,4	2413	276,3	3,92
Mean				2408	254,6	3,61
Standard deviation				5	19,0	0,27

Reg. no. : 11
Report no. : 53458-4
Date : 1997-01-02

Appendix : 1

Splitting Tensile Strength according to DS 423.34

Date of casting: 1996-11-05
Date of testing: 1996-11-19

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
7	342,3	150,1	301,0	2422	271,0	3,82
10	342,4	149,8	300,7	2399	245,0	3,46
25	342,2	150,5	300,2	2400	254,1	3,58
Mean				2407	256,7	3,62
Standard deviation				13	13,2	0,18

Splitting Tensile Strength according to DS 423.34

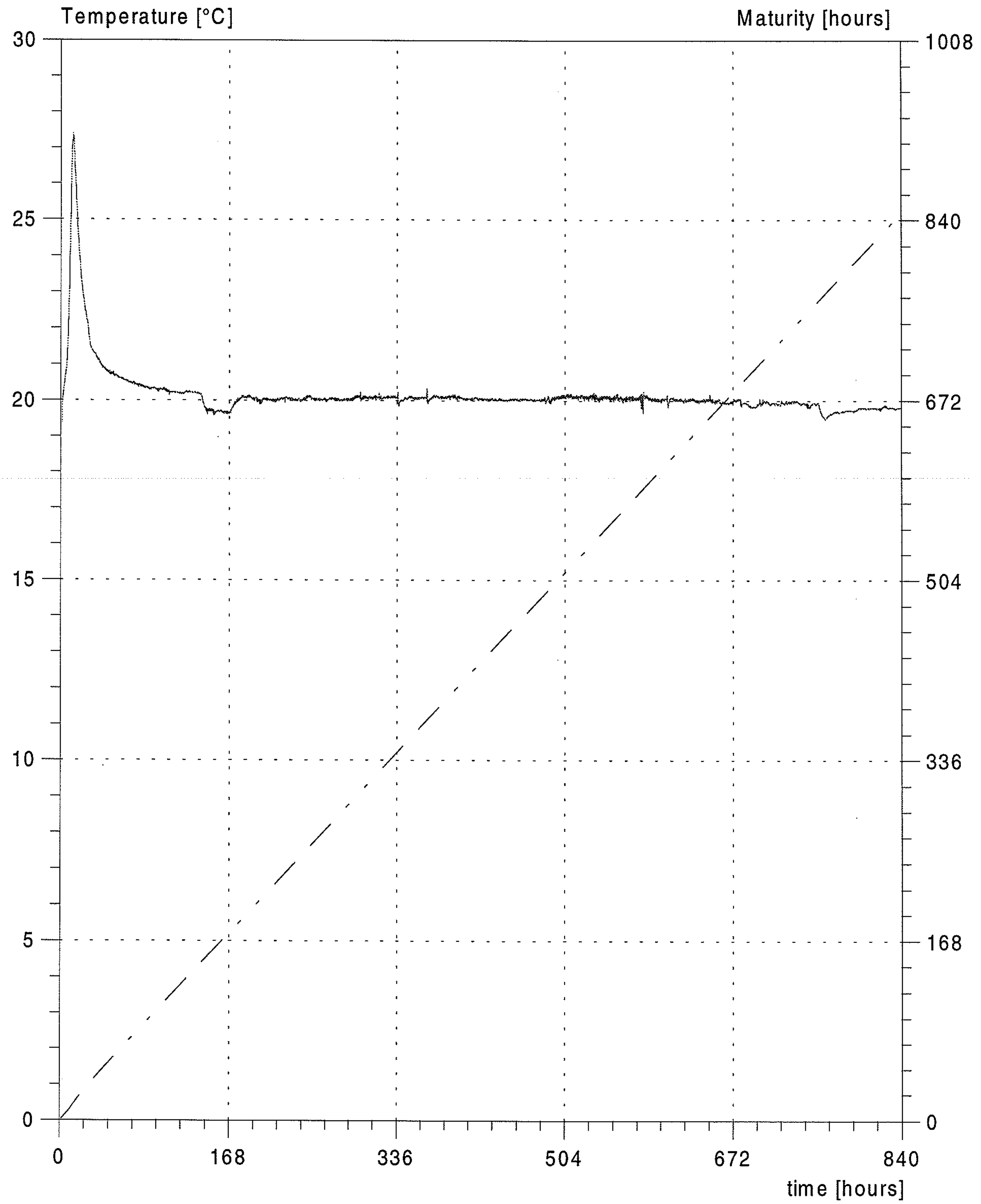
Date of casting: 1996-11-05
Date of testing: 1996-12-03

Spec. Mark	Maturity hours	Dia-meter mm	Heigth mm	Densi-ty kg/m³	Fail. load kN	Split. tens. strength MPa
32	678,0	150,0	300,0	2438	253,2	3,58
33	678,0	150,0	300,2	2430	315,0	4,45
35	678,0	150,0	300,4	2415	317,0	4,48
Mean				2428	295,1	4,17
Standard deviation				12	36,3	0,51

APPENDIX 6

Temperatures

DTI Building Technology Gregersensvej, 2630 Taastrup	Temperature and maturity as func. of time
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Init.: KER Date: 02/07/97

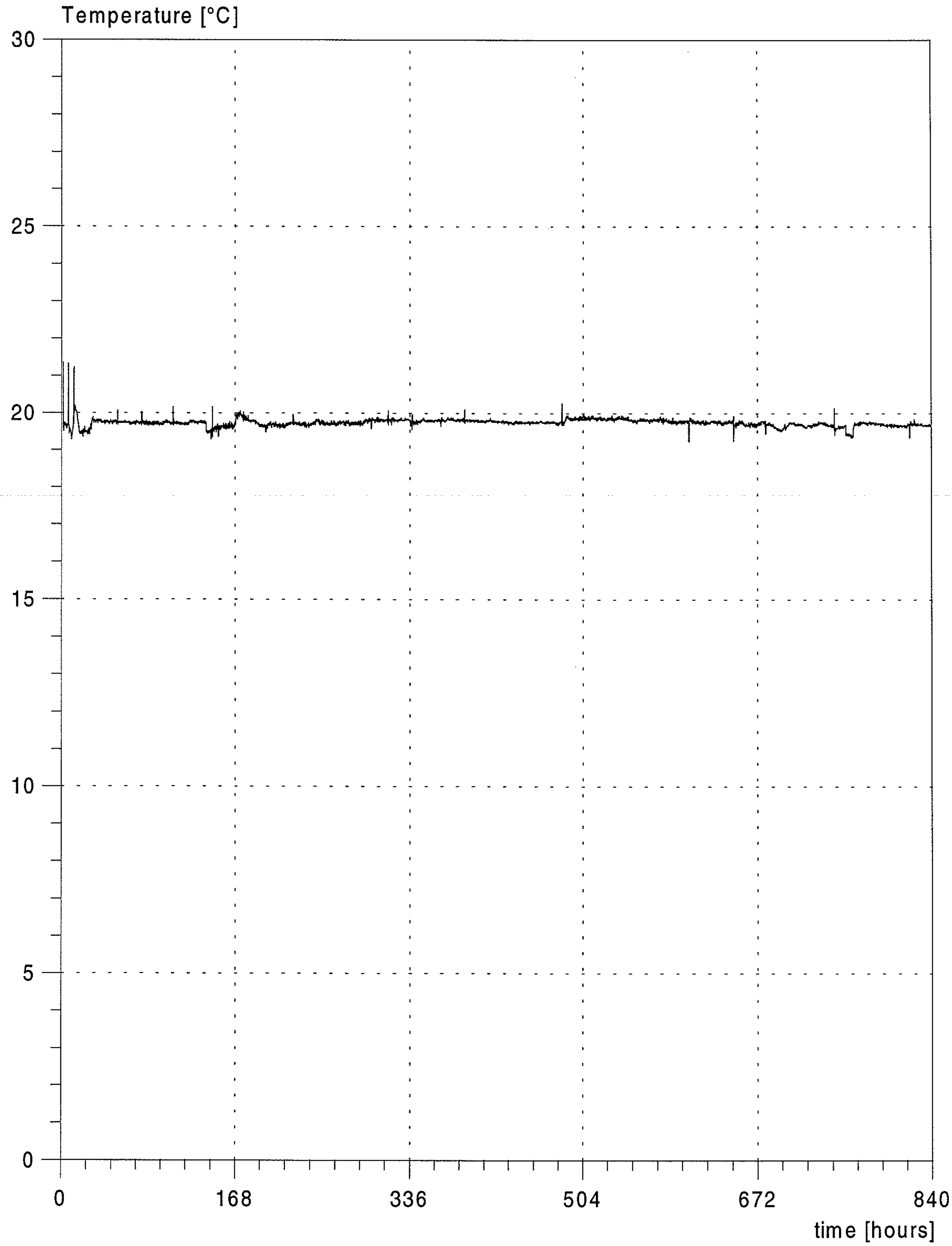


t = 0 at time of mixing

concrete temp. - spec. 5

maturity

DTI Building Technology Gregersensvej, 2630 Taastrup	Air Temperature as func. of time
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Init.: HSP Date: 02/07/97

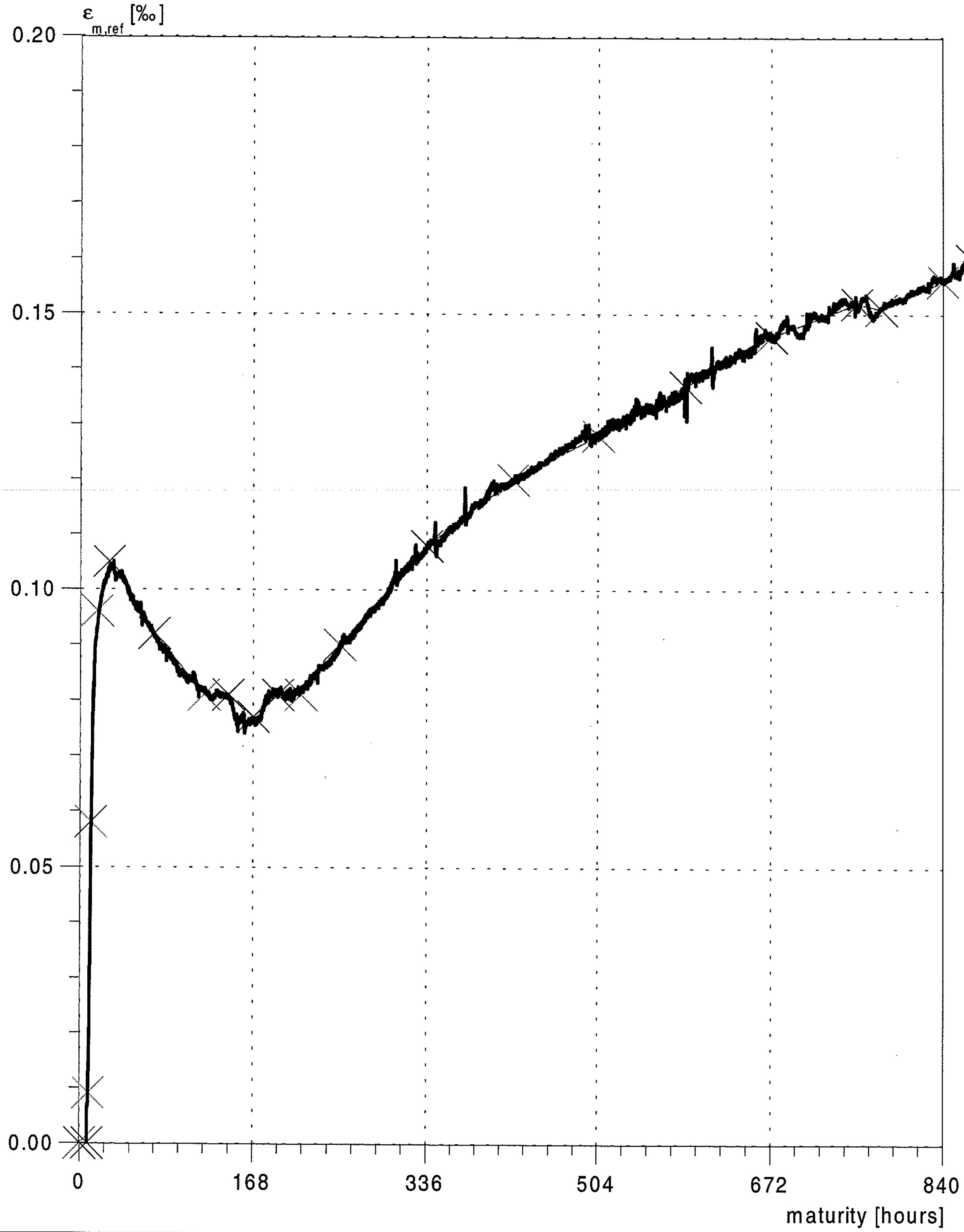


t = 0 at time of mixing	—— air temp.

APPENDIX 7

Shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage as func. of maturity
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Init.: KER Date: 02/07/97



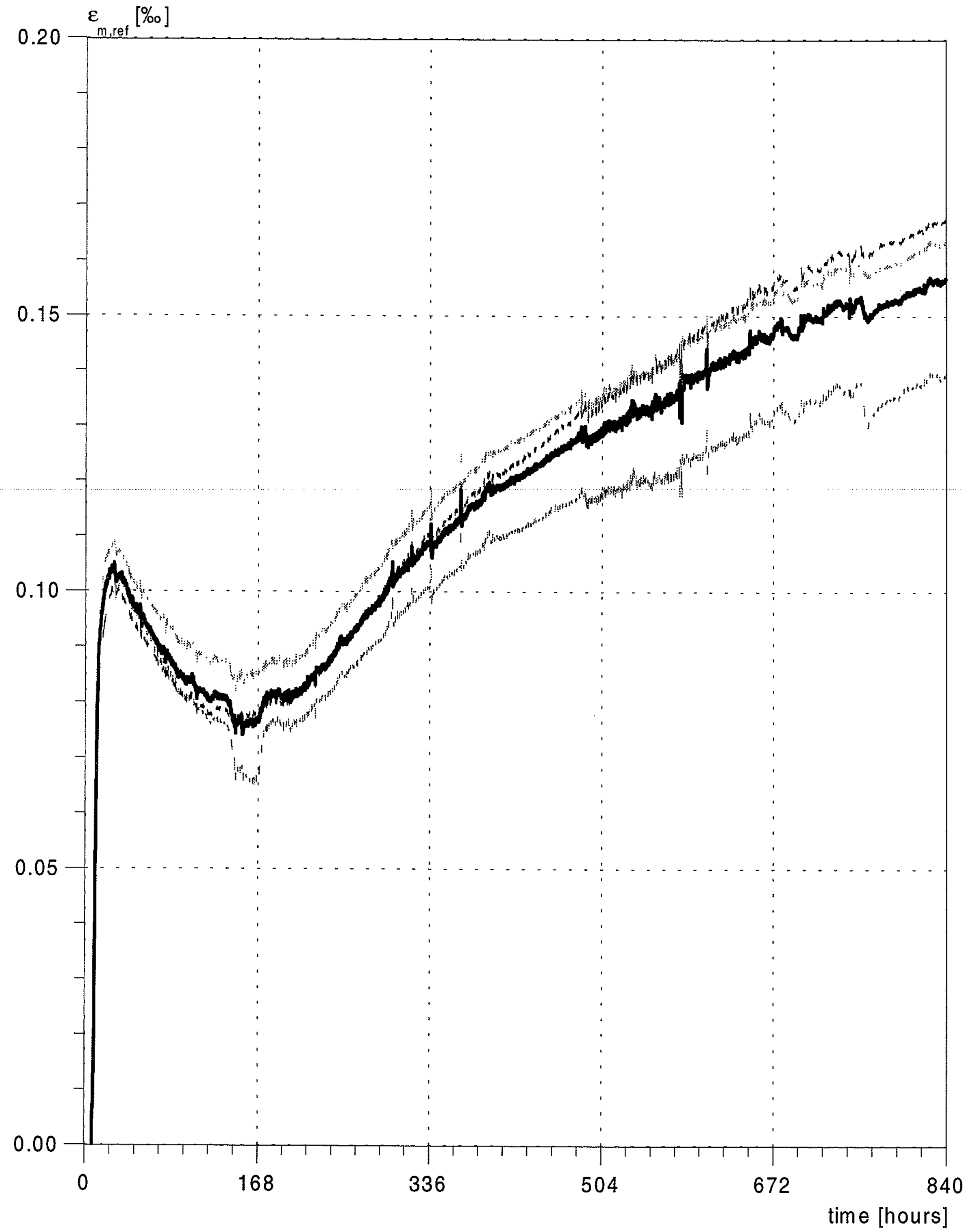
M = 0 at time of mixing

mean shrinkage

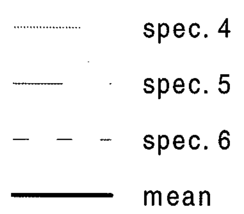
idealised shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 4, 5 og 6

Client: HETEK 3 + 4	Ref.: 53458	Init.: KER
Name: Stage 6	Date: 02/07/97	



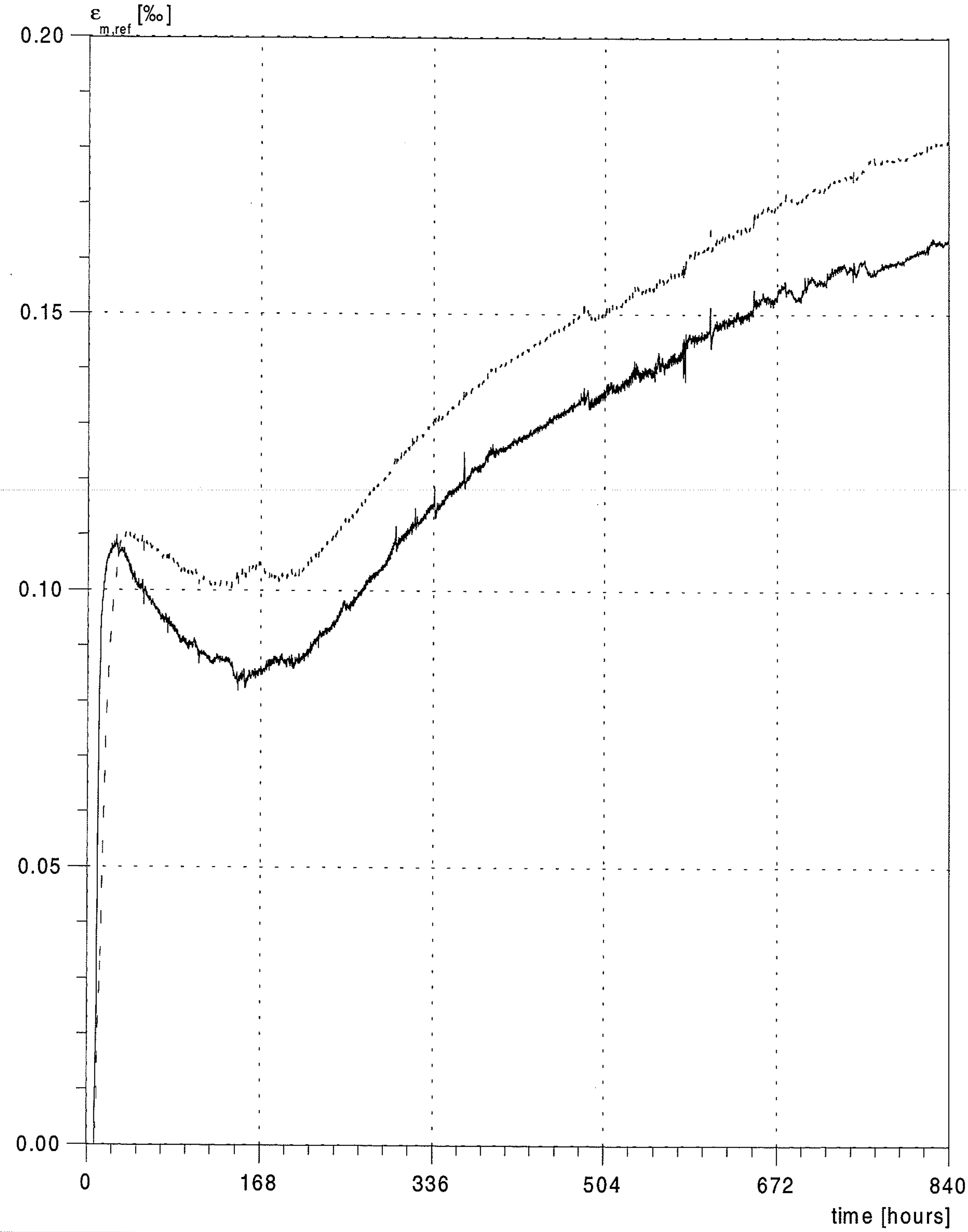
t = 0 at mixing time



DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 4

Client: HETEK 3 + 4
Name: Stage 6

Ref.: 53458 Init.: KER
Date: 02/07/97

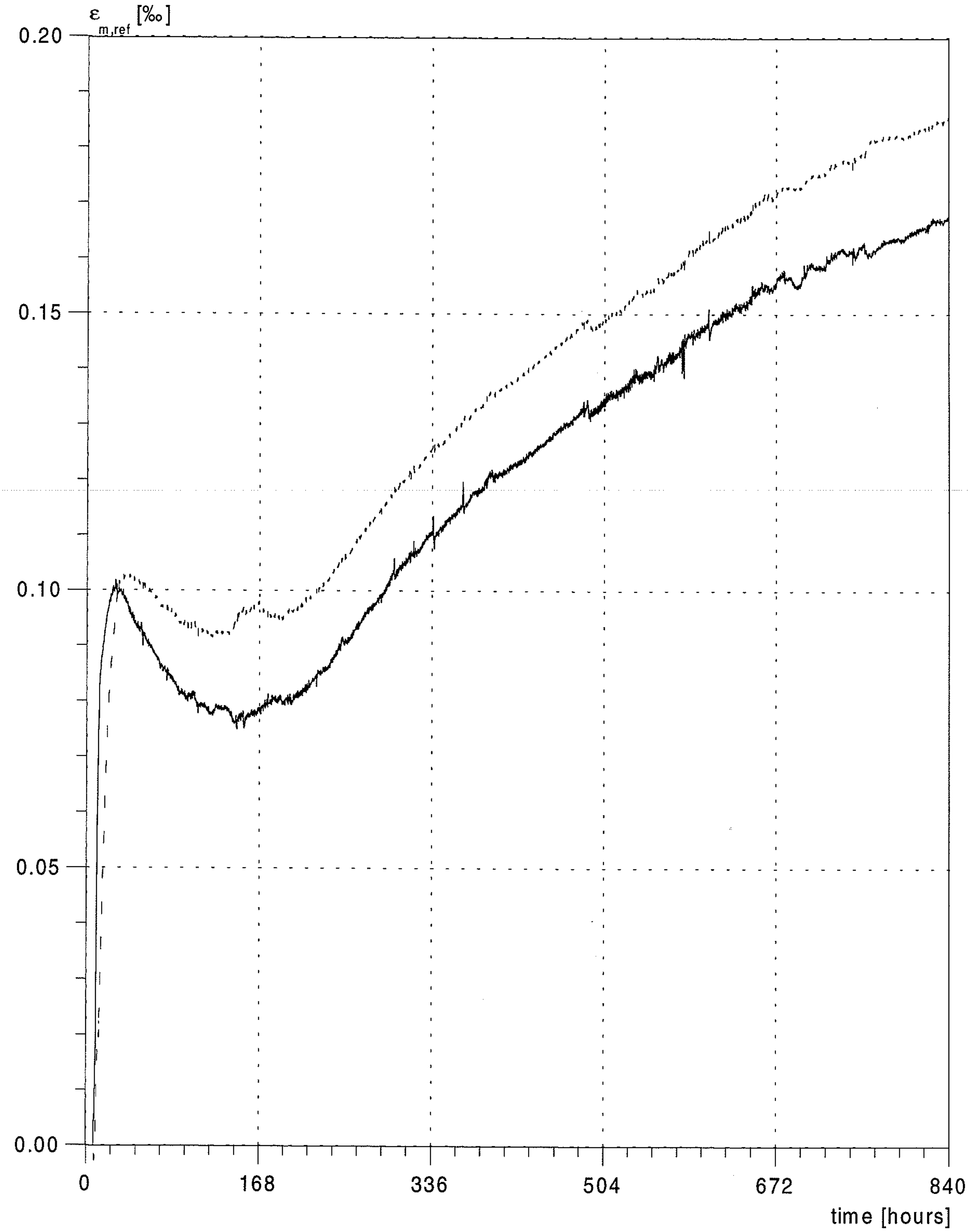


t = 0 at time of mixing

– – – mean strain in concrete

——— mean shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 5	
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



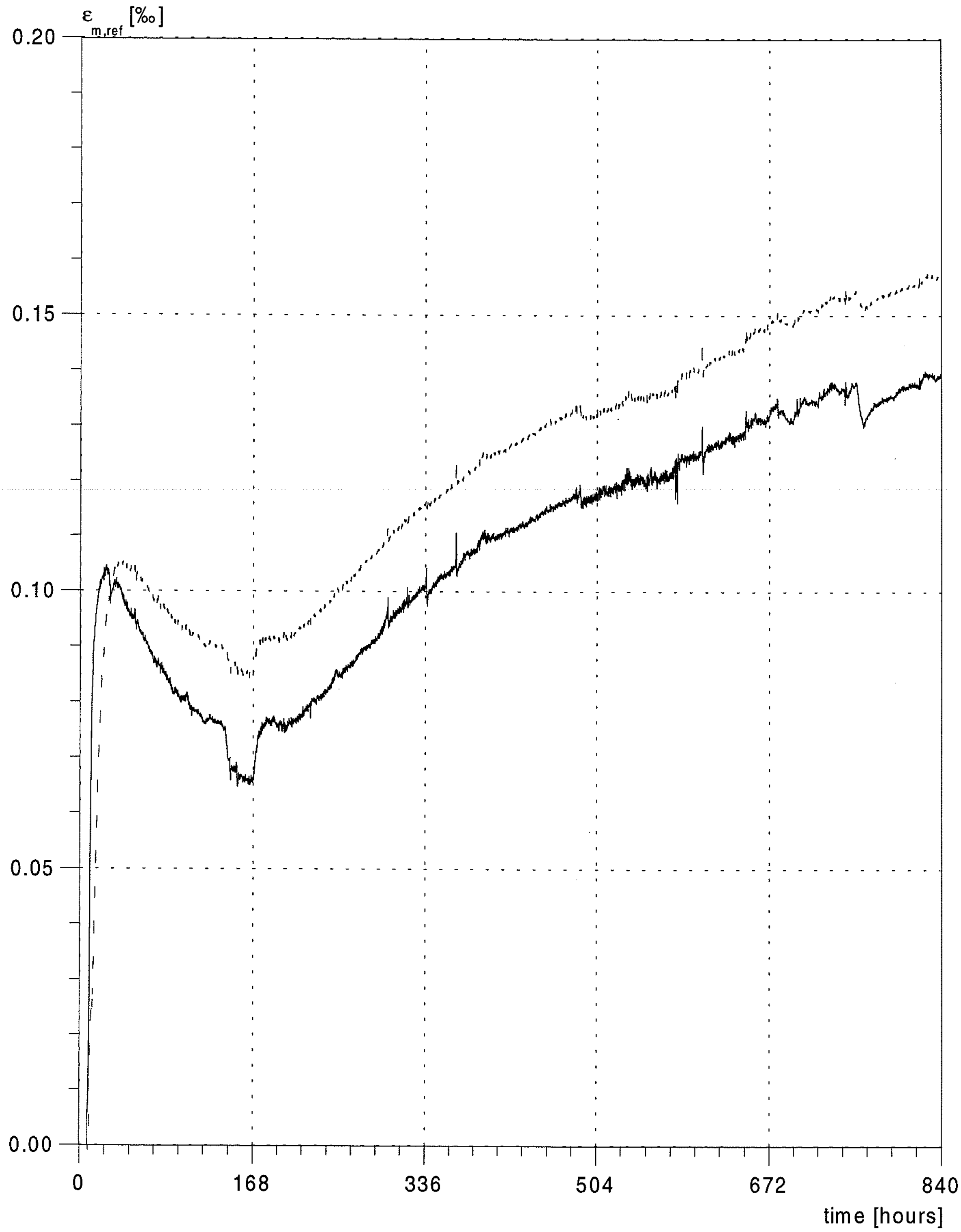
t = 0 at time of mixing

– – – mean strain in concrete

—— mean shrinkage

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain due to shrinkage spec. 6

Client: HETEK 3 + 4	Ref.: 53458	Init.: KER
Name: Stage 6	Date: 02/07/97	



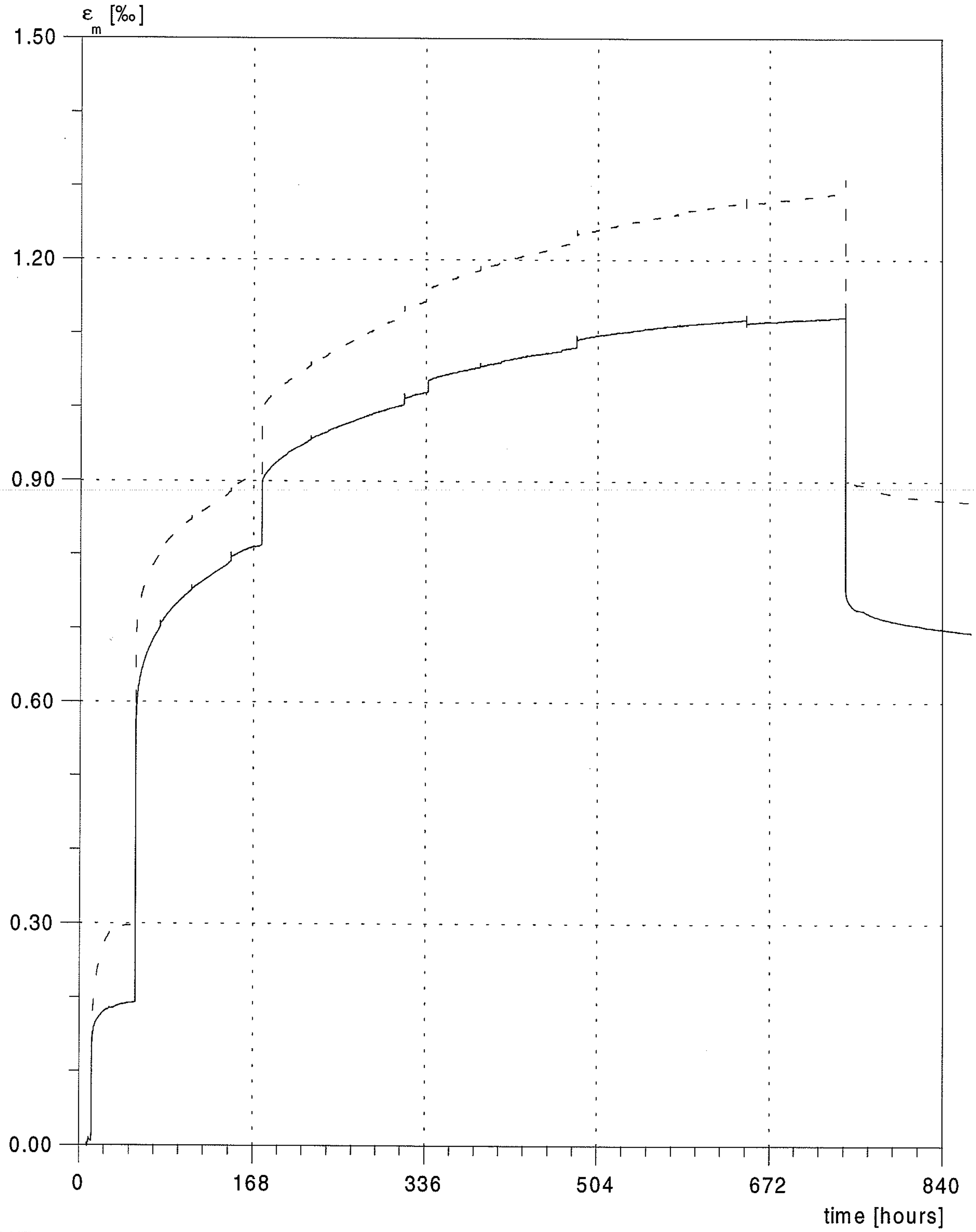
t = 0 at time of mixing	– – – mean strain in concrete —— mean shrinkage

APPENDIX 8

Strains in loaded specimens

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain in concrete and due to external load spec. 1

Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER

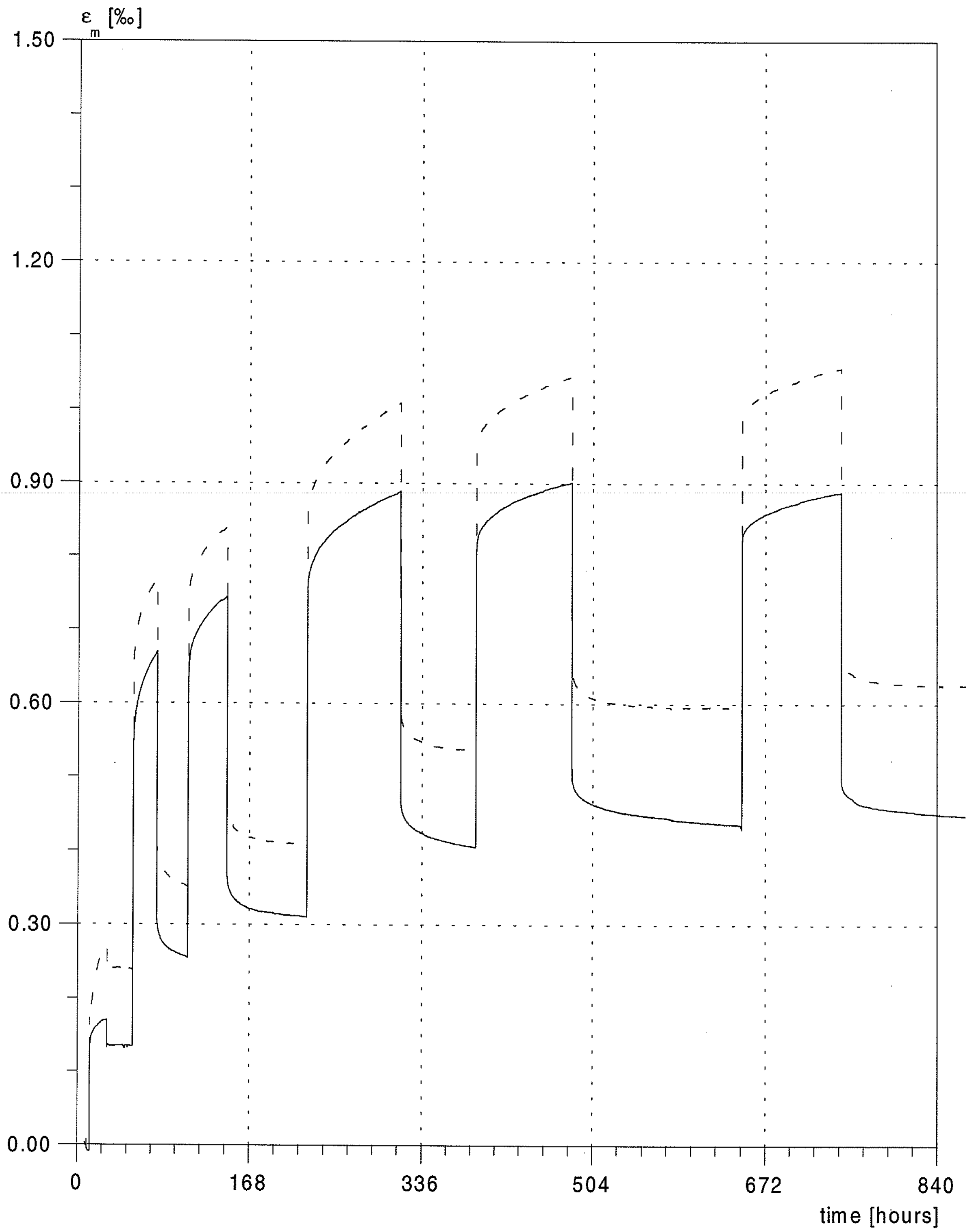


t = 0 at time of mixing

– – – measured strain in concrete

——— strain due to external load

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain in concrete and due to external load spec. 2	
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER

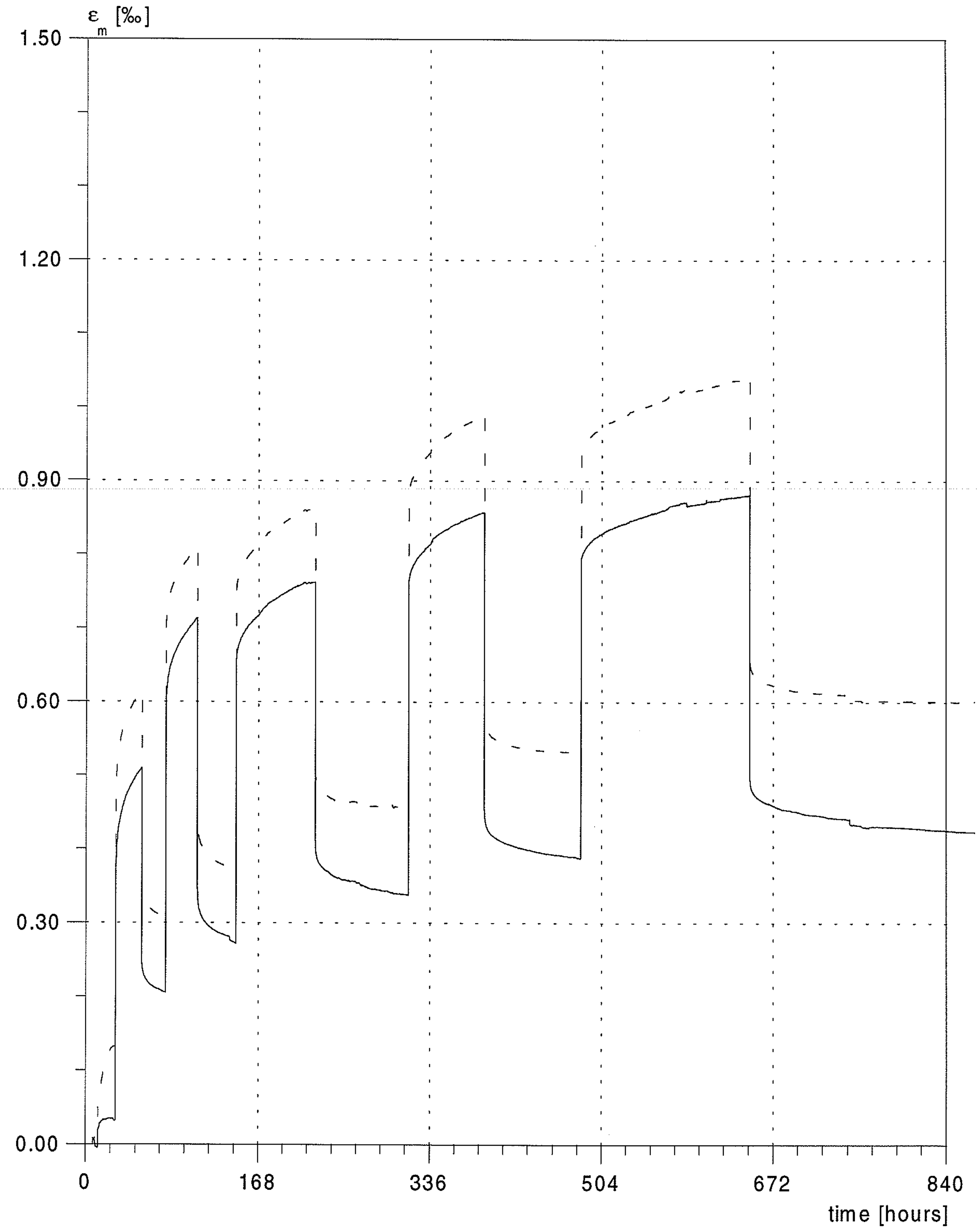


t = 0 at time of mixing

– – – measured strain in concrete

—— strain due to external load

DTI Building Technology Gregersensvej, 2630 Taastrup	Strain in concrete and due to external load spec. 3
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Init.: KER Date: 02/07/97



t = 0 at time of mixing

– – – measured strain in concrete

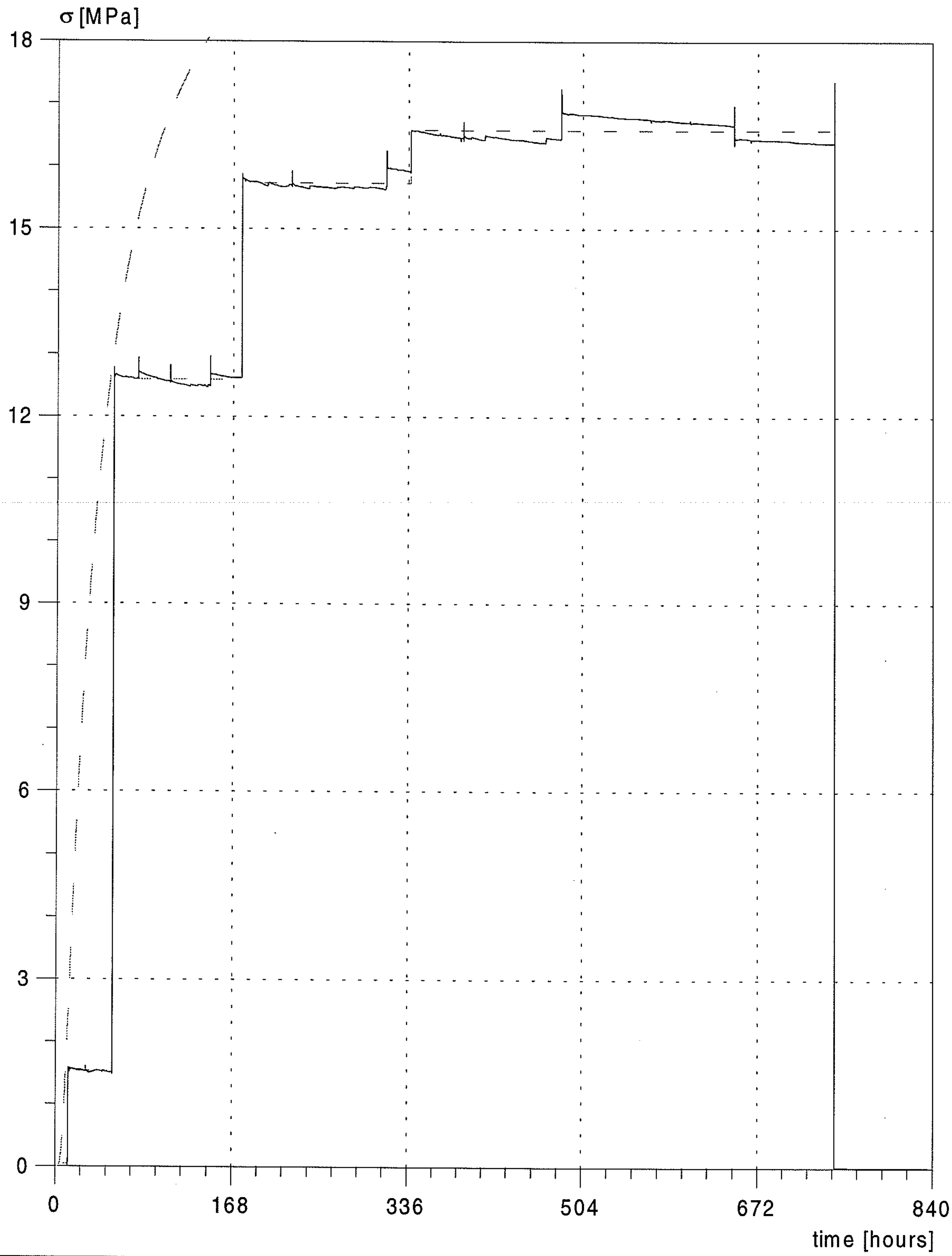
——— strain due to external load

APPENDIX 9

Load Histories

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 1

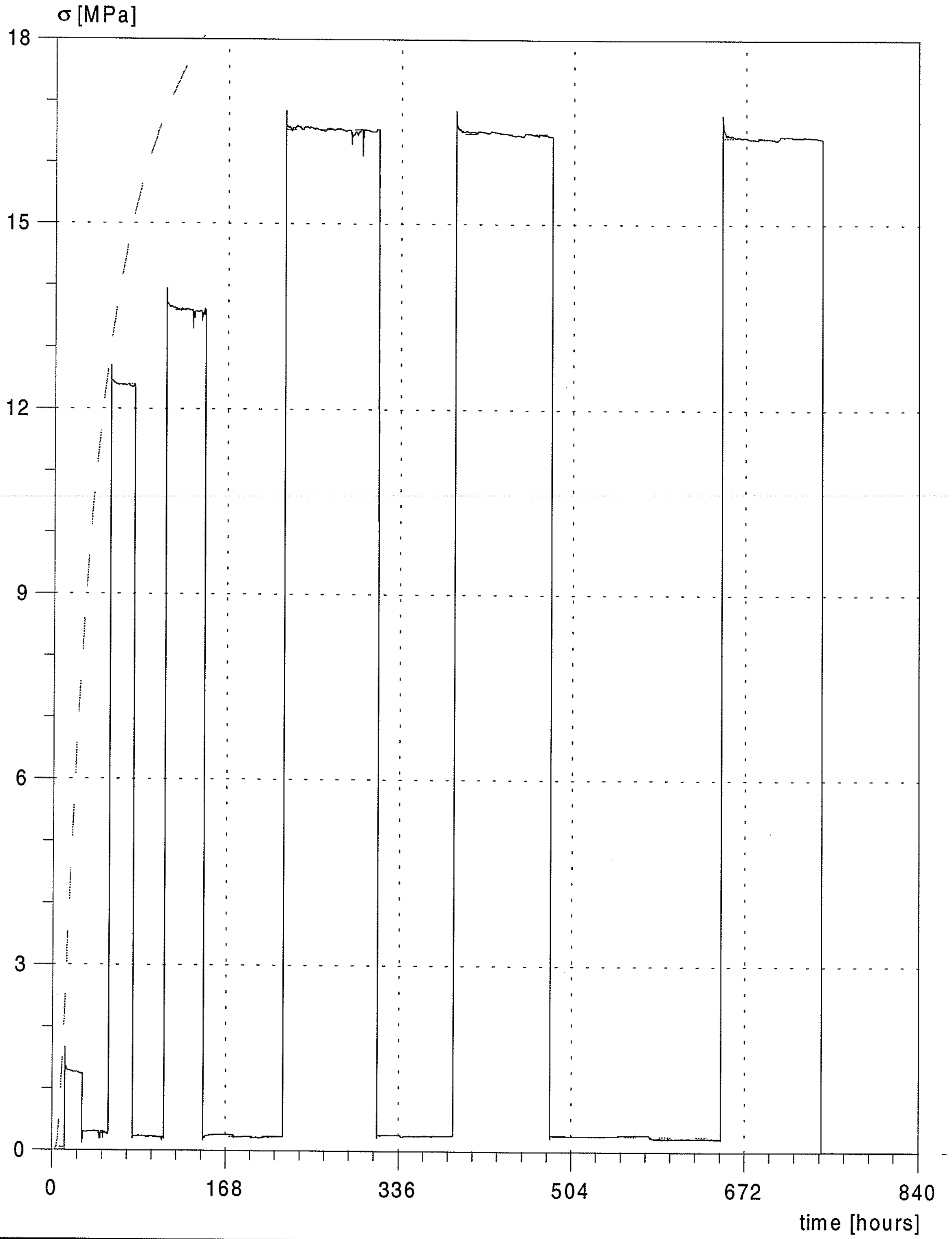
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



t = 0 at time of mixing	– – – load - idealised ——— load - measured ········ 40 % comp. strength

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 2

Client: HETEK 3 + 4	Ref.: 53458	Init.: KER
Name: Stage 6	Date: 02/07/97	



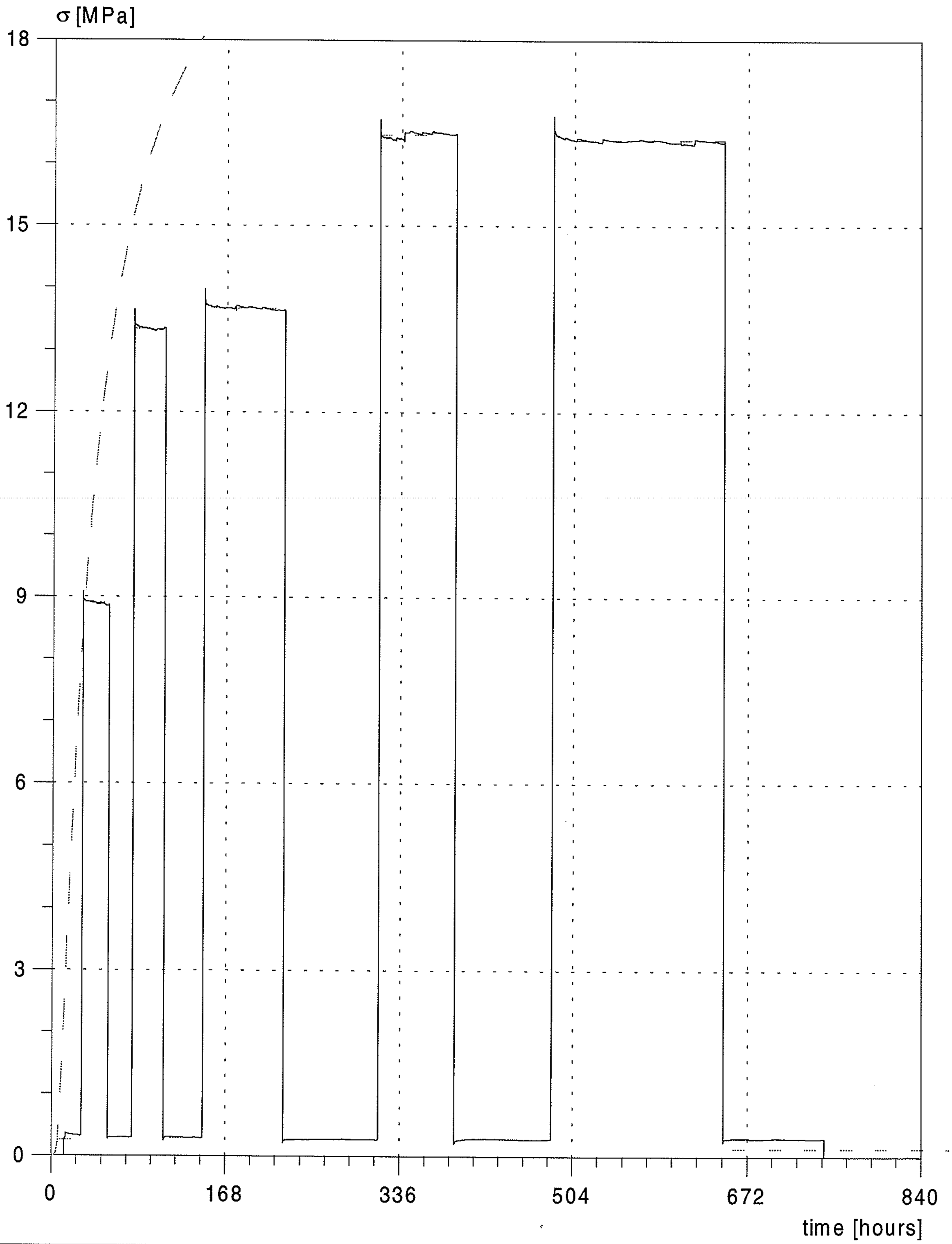
t = 0 at time of mixing

load - idealised

load - measured

40 % of comp. strength

DTI Building Technology Gregersensvej, 2630 Taastrup	Load history spec. 3	
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



t = 0 at time of mixing

load - idealised

load - measured

40 % of comp. strength

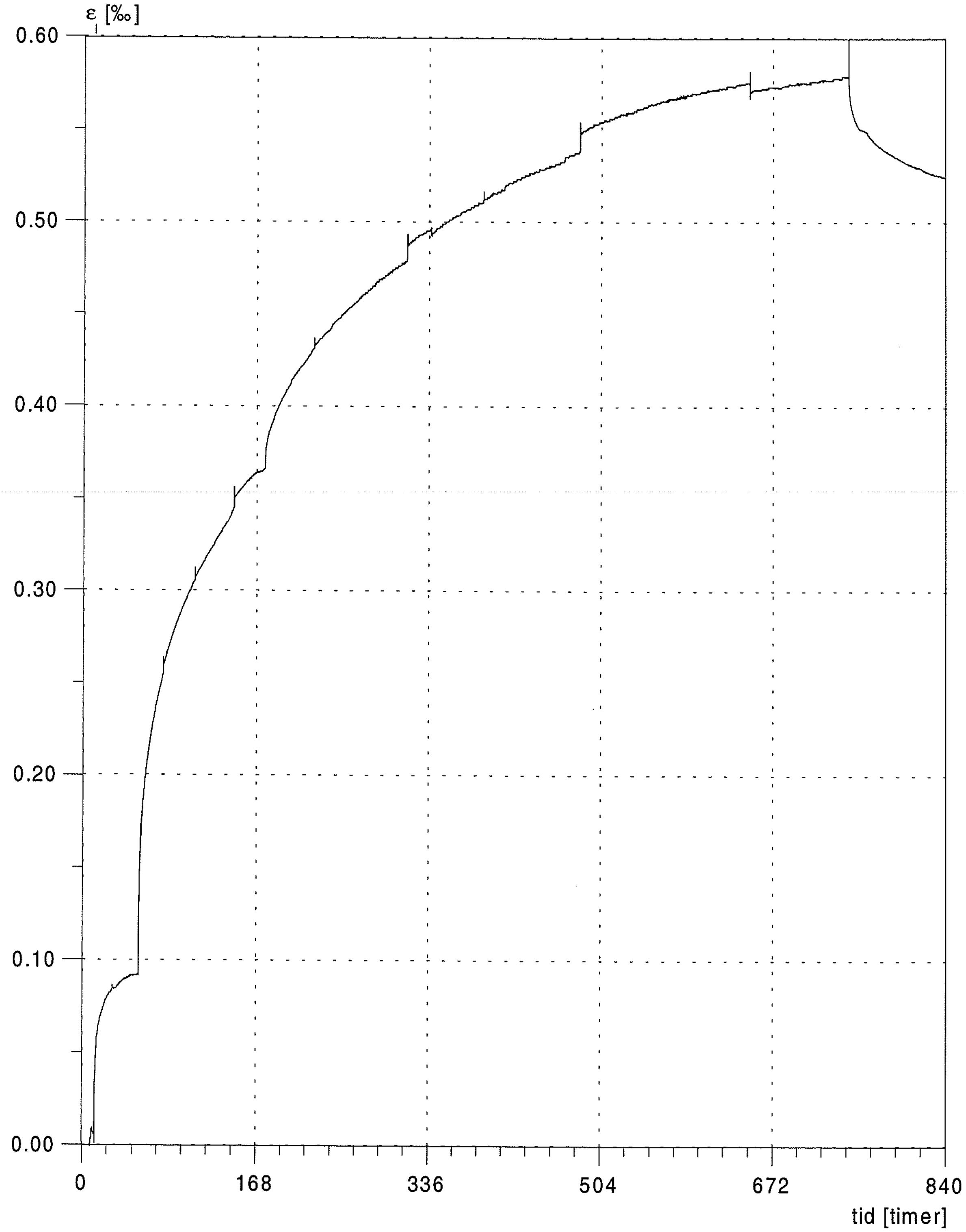
APPENDIX 10

Creep Strains

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 1

Client: HETEK 3 + 4
Name: Stage 6

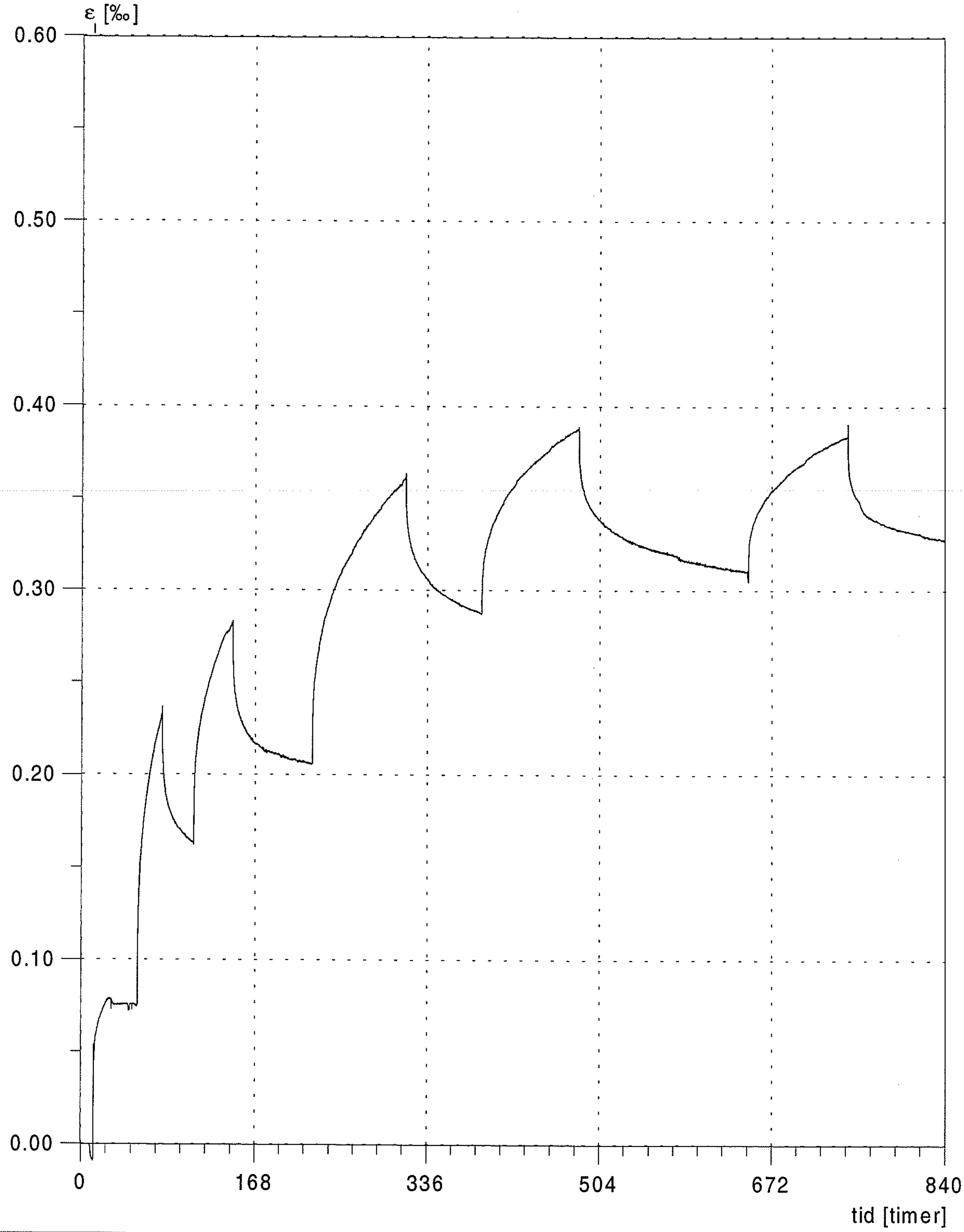
Ref.: 53458 Init.: KER
Date: 02/07/97



t = 0 at time of mixing

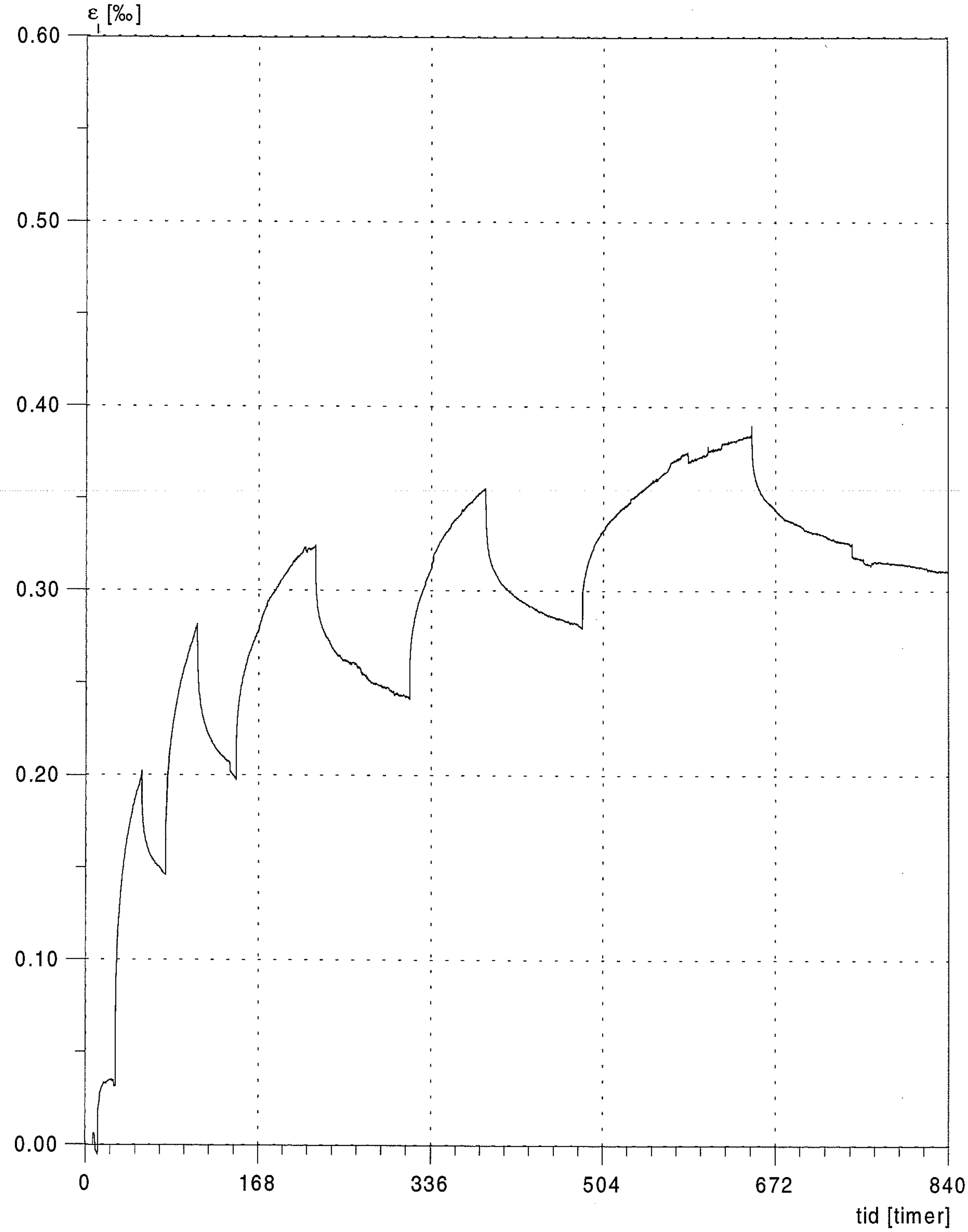
creepstrain

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 2	
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



t = 0 at time of mixing	—— creepstrain

DTI Building Technology Gregersensvej, 2630 Taastrup	Creep Strain spec. 3
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Init.: KER Date: 02/07/97



t = 0 at time of mixing

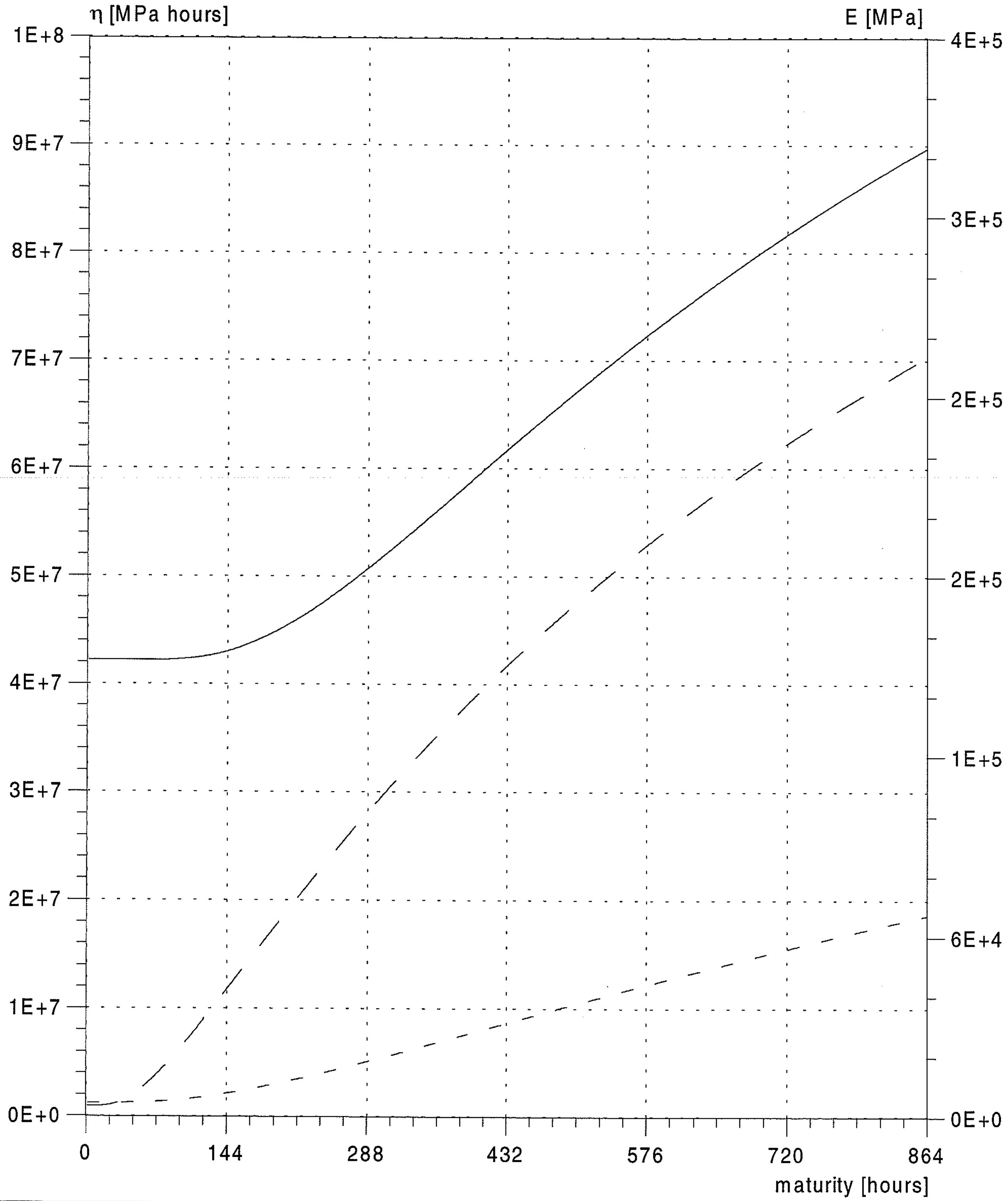
creepstrain

APPENDIX 11

Development of Creep Parameters

DTI Building Technology Gregersensvej, 2630 Taastrup	**Creep parameters** as func. of maturity

Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



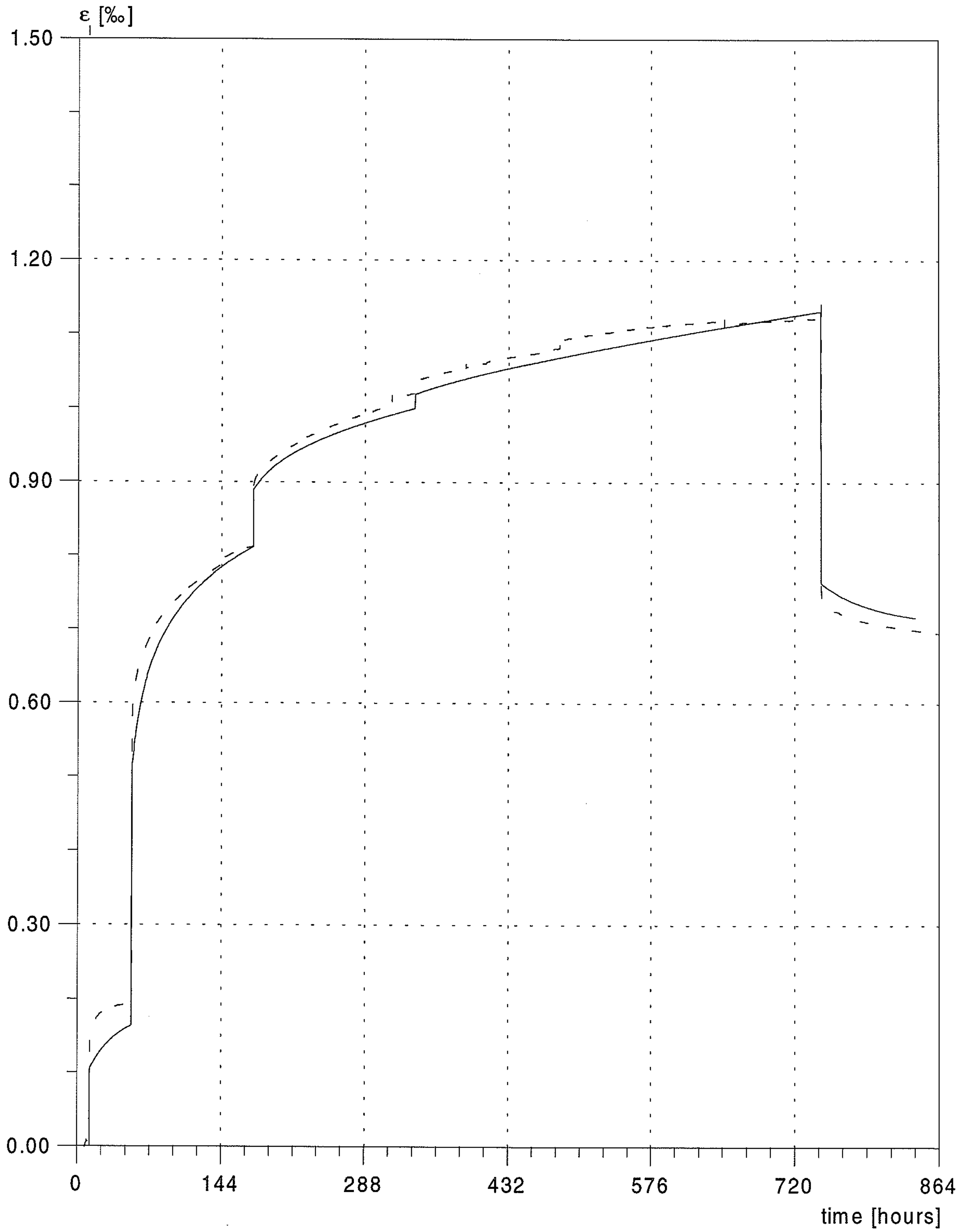
t = 0 at time of mixing	— — η_1 - - - η_2 —— E

APPENDIX 12

Calculated Strains

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 1

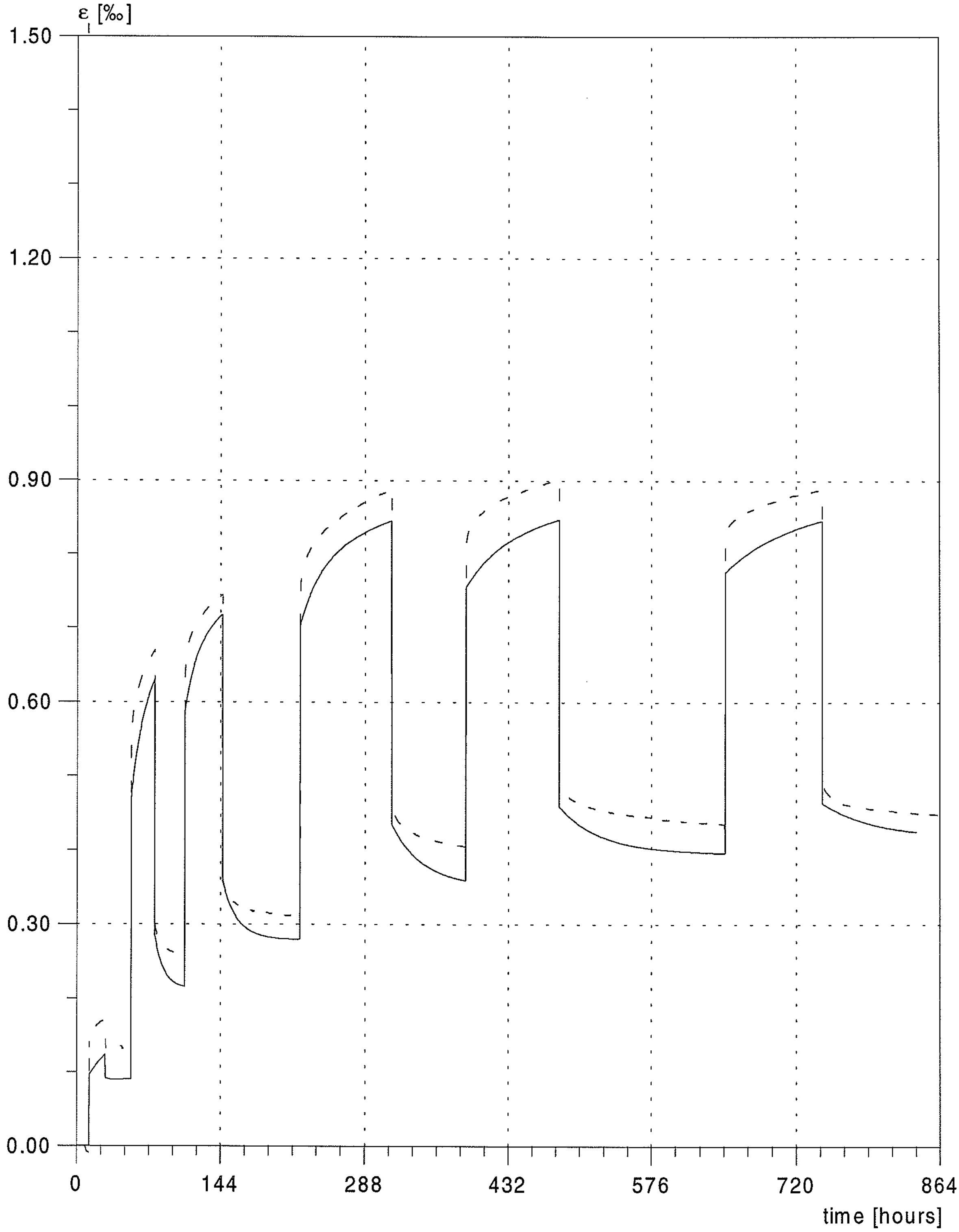
Client: HETEK 3 + 4 Name: Stage 6	Ref.: 53458 Date: 02/07/97	Init.: KER



t = 0 at time of mixing	– – – measured ——— calculated

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 2

Client: HETEK 3 + 4	Ref.: 53458	Init.: KER
Name: Stage 6	Date: 02/07/97	



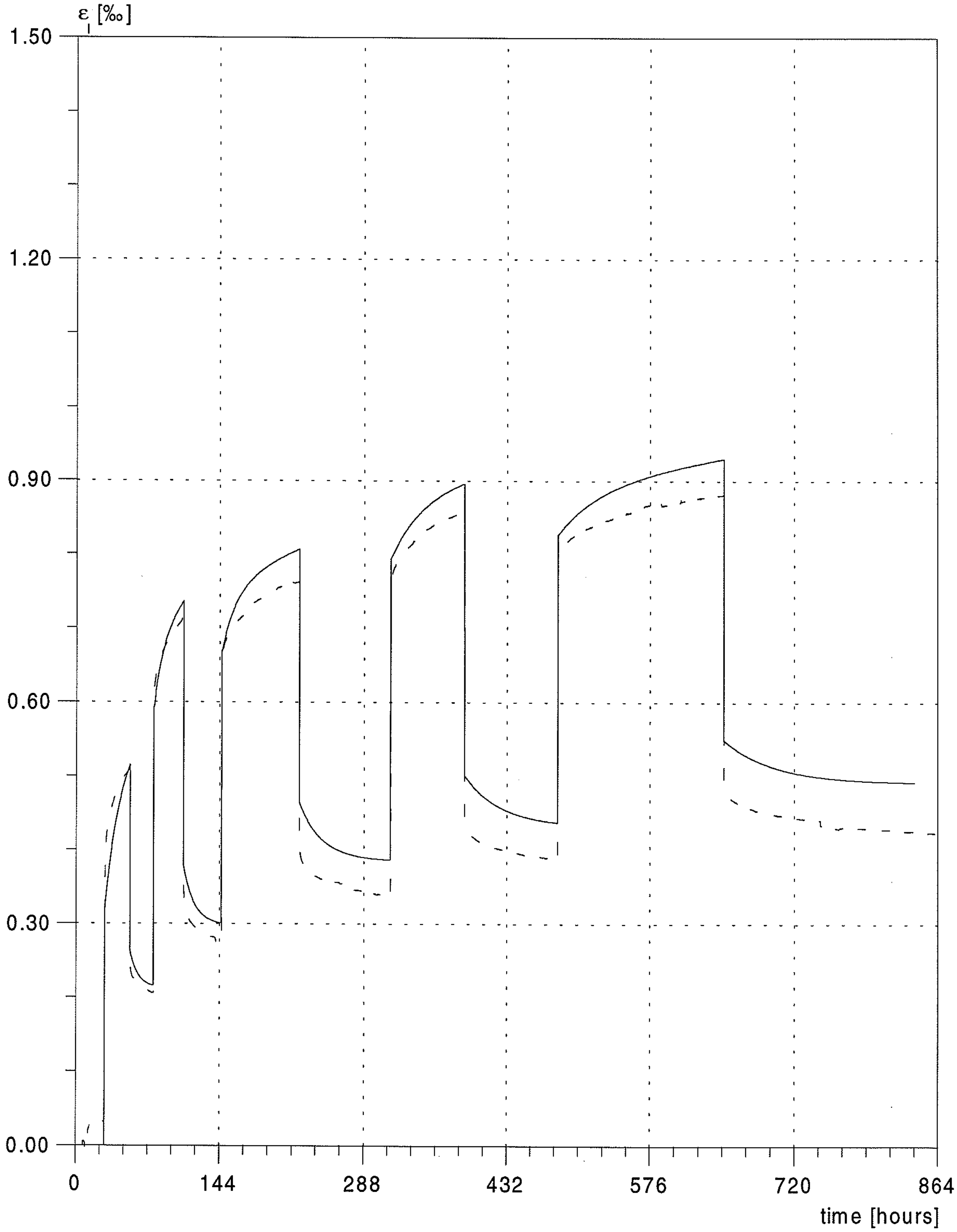
t = 0 at time of mixing

– – – measured

——— calculated

DTI Building Technology Gregersensvej, 2630 Taastrup	Calculated strain spec. 3

Client: HETEK 3 + 4	Ref.: 53458	Init.: KER
Name: Stage 6	Date: 02/07/97	



t = 0 at time of mixing	– – – measured ——— calculated

APPENDIX 13

TI-B 101

TI-B 101

Test Method
Concrete
Thermal Expansion
Coefficient

Concrete Centre *DTI Building Technology*

Test Method
Concrete
Thermal Expansion Coefficient

Descriptors:

Concrete, Thermal Expansion Coefficient

Version: 1
Date: March 1996
Pages: 4
Approved:

Test Method
Concrete
Thermal Expansion Coefficient

0. Foreword

This TI-B method replaces DTI-method "Test method for Thermal Expansion Coefficient of concrete."

1. Background and Scope

This TI-B method describes a method for the determination of the thermal expansion coefficient of concrete in the temperature range of 5°C to 30°C on sealed test specimens. The test specimens are exposed to change in temperatures in the specified temperature range. For each change in temperature the longitudinal deformation (expansion) is measured.

2. References

NT BUILD 367
Concrete, repair materials: Coefficient of Thermal Expansion

3. Definitions

Thermal expansion: change in length due to thermal variations.

Thermal expansion coefficient:

α = $\Delta\varepsilon/\Delta T$
α = thermal expansion coefficient [$°C^{-1}$]
$\Delta\varepsilon$ = strain [m/m]
ΔT = change in temperature [°C]

4. Test Method

This test method determines the thermal expansion coefficient of concrete. The thermal expansion is measured on concrete specimens at three different temperatures. The measured thermal expansion coefficient is corrected with regard to the temperature sensitivity of the measuring device and with regard to the shrinkage of the concrete.

The change in length, caused by the change in temperature in the range of 5°C to 30°C, is compared to the length l_0 at 20°C at the beginning of the test.

The test specimens are exposed to changes in temperature in the range of 5°C to 30°C. See Figure 1.

The temperatures are obtained by storing the sealed test specimens in a water bath with a constant temperature (± 1°C).

The length between the measuring points on each test specimen is measured when the test specimen is in thermal balance, i.e. the difference between the temperature in the middle of the test specimen and the temperature of the water is less than ± 1°C. The seal on each test specimen is shortly removed during the measurement.

The lengths l_0, l_1 and l_2 between the measuring points are measured at 20°C at the beginning, in the middle and at the end of the test procedure.

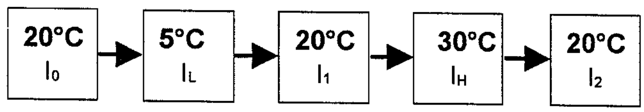


Figure 1 Changes in temperature and length measurements on the test specimens

5. Equipment

A measuring device for measuring the length changes with a strain accuracy of minimum $10 \cdot 10^{-6}$ [mm/mm]. See example in annex.

Thermocouples for measuring the temperature in the middle of at least 1/3 of all test specimens and in the water baths with an accuracy of ± 1°C.

Three water baths with a water temperature of 5°C, 20°C and 30°C.

6. Test Specimens

A set of test specimens consists of at least three concrete prisms of 100x100x400 mm. The prisms are sealed in a heavy plastic bag and stored in a water bath at 20°C until testing.

7. Procedure

The concrete prisms are cast as described in DS 423.21 for cubes.

The forms are removed and possible surface defects are reported.

After removing the forms each test specimen is given a number and the measuring points are placed according to the test method, see annex.

The test specimens are sealed in a heavy plastic bag and stored in a water bath at 20°C.

A measurement is carried out as follows:

- Report starting hour
- Measure the temperature in the water bath and the test specimens
- Measure the length between the measuring points. This procedure is repeated for all test specimens
- Measure the temperature in the test specimens
- Report ending hour.

During the test the change in temperature and the measurements are carried out according to the following items:

1 The test specimens are removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

2 The test specimens are sealed in the plastic bag and placed in the water bath at 5°C.

3 When a test specimen is in thermal balance at 5°C (± 1°C) it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

4[1] The test specimens are sealed in the plastic bag and placed in the water bath at 20°C.

5[1] When a test specimen is in thermal balance at 20°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

6 The test specimens are sealed in the plastic bag and placed in the water bath at 30°C.

7 When a test specimen is in thermal balance at 30°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

8 The test specimens are sealed in the plastic bag and placed in the water bath at 20°C.

9 When a test specimen is in thermal balance at 20°C (± 1°C), it is removed from the water bath and the plastic bag and isolated until measuring. A measurement is carried out.

After this procedure the test specimens are sealed in the plastic bag and stored at 20°C, if the measurement has to be repeated at another term.

8. Test Result

The measured lengths are corrected with regard to the temperature sensitivity of the measuring device and with regard to the shrinkage of the concrete. The corrections are made on the following conditions:

- A difference in the measured lengths at 20°C are due to shrinkage in the concrete. The shrinkage is assumed to take place linearly in time.

The corrected change in length between the measurements l_H (30°C) and l_L (5°C) is used to calculate the thermal expansion coefficient. The thermal expansion coefficient is calculated according to the following formula:

$$\alpha = \frac{\Delta l}{l_0 \cdot \Delta T}$$

α = thermal expansion coefficient, [1/°C]
Δl = corrected change in length, [m]
l_0 = actual measured length at 20°C at the beginning of the test, [m]
ΔT = temperature difference at the measured lengths, °C.

The test results are reported as average and standard deviation.

[1] Items 4 and 5 may be omitted in case of late terms.

9. Calibration

The measuring device must be in calibration at the time of testing and must be calibrated according to the instructions for this type of device.

10. Data Accuracy

Repeatability: if normal care and accuracy are shown, it can be expected that the test can be repeated with a 95 % confidence range for an average value of approximately ± 0.03 10^{-5}.

Reproducibility: if normal care and accuracy are shown, it can be expected that the test can be repeated with a 95 % confidence range for an average value of approximately ± 0.05 10^{-5}.

11. Test Report

A test report shall include at least the following information:

a) Name and address of testing laboratory.
b) Date and identification of the report.
c) Name and address of the client.
d) Test method (No. and title).
e) Deviations from the test method, if any.
f) Identification of the concrete:
Date of receipt of test specimens/selections.
Description of test specimens/selections.
Marking of test specimens e.g. mix design, casting specification etc.
g) Date of test period.
h) Records of surface defects.
i) Measuring equipment.
j) Test result.
k) Further information of significance for the evaluation of the result.
l) Evaluation of the result, if included in the assignment.
m) Signature.

Example of a measuring device: DEMEC measuring device type MAYERS, model MD with a measuring length of 200 mm and an accuracy of 0.002 mm.

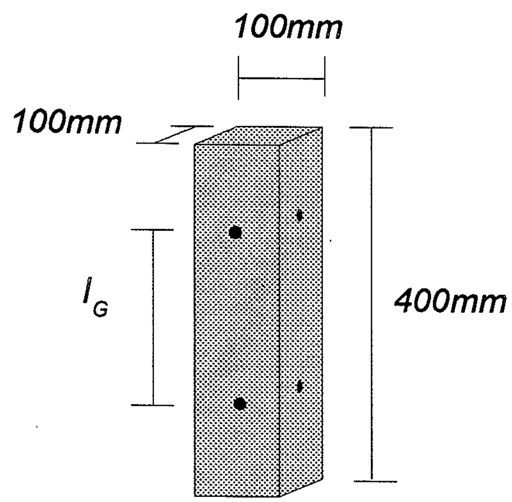


Figure 2 DEMEC: measuring points and dimensions of the test specimens.

Example of a measuring device: SYLVAC measuring device model 100 with a measuring length of 400 mm and an accuracy of 0.001 mm.

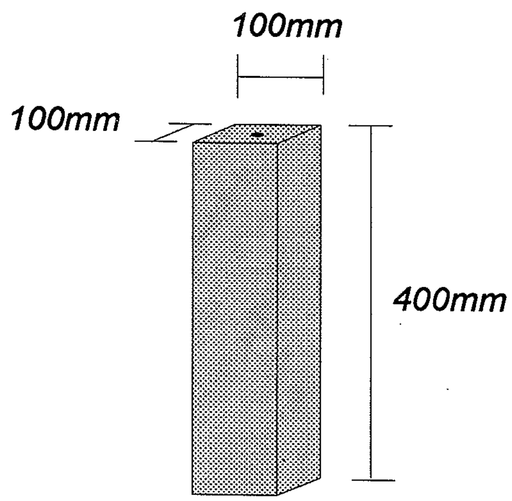


Figure 3 SYLVAC: measuring points and dimensions of the test specimens.

APPENDIX 14

TI-B 102

TI-B 102

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

Concrete Centre *DTI Building Technology*

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

Descriptors:

Concrete, Creep and Early-Age Shrinkage

Version: 1
Date: March 1996
Number of pages: 5
Number of pages, Annex A: 3
Number of pages, Annex B: 3
Approved:

Test Method
Concrete
Strains from Creep and Early-Age Shrinkage

1. Scope and Area of application

This test method is applied for determination of creep strain and/or strain caused by early-age shrinkage of concrete. The method does not include determination of strains caused by desiccation shrinkage, nor does it cover creep strains caused by tension. The strains are determined as a function of the age of the concrete. The determination takes place during a period of 28 days unless other requirements are stipulated.

2. References

DS423.12 Testing of Concrete. Consistency of fresh concrete. Slump test.

DS423.15 Testing of Concrete. Determination of the content of airvoid in fresh concrete.

DS423.16 Testing of Concrete. Fresh concrete. Density.

DS423.17 Testing of Concrete. Fresh concrete. Hardening.

DS423.21 Testing of Concrete. Making and curing of moulded test specimens for strength tests.

DS423.23 Testing of concrete. Hardened concrete. Compressive strength.

ASTM - C1074. Standard Practice for Estimating Concrete Strength by the Maturity Method.

TI-B 101 Test Method. Thermal Expansion Coefficient.

TI-B 103 Test Method. Activation Energy for the Maturity Method.

3. Definitions

The following definitions are used in this method:

3.1 Shrinkage
Deformations caused by the hardening process of the concrete with the exception of deformations caused by temperature variations and exchange of humidity with the surroundings.

3.2 Creep
Deformations caused by action from an external load with the exception of initial elastic deformations.

4. Principle of Method

4.1 Shrinkage
The shrinkage is determined as the deformations that take place in a test specimen free from load after the hardening process has started and compensation is made for deformations originating from the temperature variations in the concrete. Exchange of humidity between the test specimens and the surroundings shall be prevented.

The compensation for temperature deformations implies knowledge of the thermal expansion coefficient of the concrete. It is assumed that the thermal expansion coefficient is independent of the age of the concrete during the relevant period. The thermal expansion coefficient may be determined in accordance with TI-B 101.

The determination of shrinkage is performed on the basis of measurements on at least 3 test specimens. The concrete temperature must be measured in the middle of at least 1 specimen.

4.2 Creep
Creep is determined by repeated loading and off-loading of a number of test specimens. Exchange of humidity between the test specimens and the surroundings shall be prevented.The measured deformations are compensated for the shrinkage of the concrete and the temperature variations caused by the hardening process by means of measurements on at least 1 unloaded reference test specimen. Also the initial elastic deformations of the concrete are compensated for.

Determination of creep is made on the basis of measurements on at least 3 test specimens, and at least 1 unloaded reference test specimen. In case shrinkage at early age is determined simultaneously, the shrinkage test specimens may be used as reference. The 3 creep test specimens shall not necessarily be exposed to the same load sequences. The concrete temperature must be measured in the middle of at least 1 loaded test specimen and 1 reference test specimen.

5. Test Specimens

The test specimens are made of concrete cast in such a way that humidity exchange with the surroundings is prevented from the time of casting. It must be ensured that the concrete is not exposed to unintentional external forces (for instance friction between the test specimen and the mould).

The test specimens are cylinders with a diameter of approximately 130 mm and a height of approximately 700 mm. The thermal boundary conditions shall be coordinated so that the temperature difference within the cross section is not higher than 1 °C.

6. Equipment

6.1 General

Equipment for casting of concrete and determination of the temperature of the fresh concrete, slump, air content and density.

Moulds made of a non-absorbent material that is diffusiontight and inactive to cement.

Climate Chamber that can maintain a temperature of 20 ± 2°C.

Thermocouples for determination of the temperature of the surroundings and the temperature in the middle of a test specimen. The accuracy shall be within ± 1 °C at the absolute level. Temperature variations shall be measured within ± 0.5 °C.

Deformation gauge to measure length changes. When creep is determined the length changes shall be measured with load applied. The gauge length shall be 400 - 600 mm. The gauge is fixed at the middle of the test specimen. The measurements are carried out on two opposite sides of the specimen. It shall be possible to compensate for possible temperature sensitivity of the deformation gauge. The strain shall be measured with an accuracy of ± $5 \cdot 10^{-6}$.

6.2 Creep

Additional equipment required for determination of creep:

Equipment for application of load. A load corresponding to at least 40 % of the expected compressive strength shall be applied. The load shall be kept constant in the range of ± 5 % during the desired measuring period.

Equipment for measuring the applied load. The accuracy shall be in the range of ± 3 %.

Equipment for determination of the compressive strength of the concrete in accordance with DS 423.23.

7. Measuring Procedure

7.1 Preparation of Test Specimens

If possible the test specimens shall be cast of concrete from same batch. If possible the temperature of the concrete should be the same as that of the climate chamber at the time of the casting (refer section 7.2.1).

Slump, air content and density are determined on the fresh concrete in accordance with DS 423. Furthermore the concrete temperature is measured. The casting shall be performed according to DS 423.21 for concrete to be vibrated. After casting the moulds are closed and placed vertically in the climate chamber.

7.2 Procedure

A measurement comprises correlated values of time, deformations, temperatures and possibly load.

7.2.1 Shrinkage

The measurements shall be started as early as possible and not later than when the heat development in the concrete starts. If the casting temperature of the concrete corresponds to that of the climate chamber, the time of initial heat development can be determined as the time where the rise in the concrete temperature exceeds the rise in the temperature of the surroundings by 1 °C. [1]

Measurements are made at least every 20 minutes during the first 72 hours, then at least every hour for the next 168 hours (1 week) and at least every 6 hours for the remaining test period.

7.2.2 Creep

The measurements are started not later than by the first application of load.

Prior to each application/increase of load the compressive strength is determined according to DS 423.23 on at least 1 test specimen made with the same concrete and hardening as the test specimens used in the creep test. This might be omitted in case the strength development of the concrete is known.

---

[1] If it has not been possible to cast the concrete at the same temperature as that of the climate chamber, it will be difficult to determine whether the temperature variations in the concrete have been caused by heat exchange with the surroundings or by heat development in the concrete. In that case the starting time may be fixed as the time where the penetration resistance determined according to DS 423.17 exceeds 3.5 MPa, and the starting time as well as the setting period determined according to DS 423.17 shall be stated in the report.

During each application and relief of load at least 5 correlated values of load and deformations are recorded. Measurements are made at least every 20 minutes during the first 72 hours after loading and off-loading, respectively, then at least once every hour during the following 168 hours (1 week) and at least every 6 hours for the remaining test period.

The application of load shall take place at a velocity where the initial elastic deformations do not significantly increase the creep process. This requirement will normally be met if the application of load takes place within a period of 5 minutes. The load should be applied centrally. The off-loading shall take place at the same velocity as the loading. The maximum load must not exceed 40 % of the compressive strength at the time of loading.

7.3 Test Result

7.3.1 General

The maturity is determined on the basis of the measured concrete temperature by means of Arhenius´ function as stated in ASTM - C1074 with the activation energy defined as in TI-B 103.

The strain of the concrete corresponding to the measurement on one side of a test specimen is determined as:

$$\varepsilon_m(t) = -\left(\frac{l_t - l_0}{l_D}\right) + \varepsilon_{T,G}(t)$$

where:

$\varepsilon_m(t)$	=	Measured strain at the time t, positive as contraction [m/m]
l_0	=	Length at the time t_0 [μm]
l_t	=	Length at the time t [μm]
l_D	=	Measuring length [μm]
$\varepsilon_{T,G}(t)$	=	Possible increase in strain caused by temperature sensitivity of the deformation gauge at the time t, positive as contraction [m/m]

The concrete strain $\varepsilon_{m,n}(t)$ measured on test specimen No. n is determined as average of measurements on two opposite sides of a test specimen.

7.3.2 Shrinkage

The shrinkage strain in test specimen No. n is determined as the measured concrete strain n in the test specimen corrected for contributions from the temperature deformations of the concrete:

$$\varepsilon_{s,n}(t) = \varepsilon_{m,n}(t) + \alpha_c(T_c(t) - T_c(t_0))$$

where:

$\varepsilon_{s,n}(t)$	=	Shrinkage strain in test specimen No. n at the time t, positive as contraction [m/m]
$\varepsilon_{m,n}(t)$	=	Concrete strain in test specimen No. n at the time t, positive as contraction [m/m]
α_c	=	Thermal expansion coefficient of the concrete
$T_c(t)$	=	Concrete temperature at the time t [m/m]
$T_c(t_0)$	=	Concrete temperature at the time t_0 [m/m]

The shrinkage strain of the concrete $\varepsilon_s(t)$ is determined as average of the shrinkage strains determined on the individual test specimens.

7.3.3 Creep

The stress applied to test specimen No. n is determined as:

$$\sigma_n(t) = \frac{1000 \cdot P_n(t)}{\frac{1}{4}\pi d^2}$$

where:

$\sigma_n(t)$	=	Stress in test specimen No. n at the time t [MPa]
$P_n(t)$	=	Load applied to test specimen No. n at the time t [kN]
d	=	Diameter of test specimen [mm]

The concrete strain caused by an external load to test specimen No. n is determined as:

$$\varepsilon_{l,n}(t) = \varepsilon_{m,n}(t) - \varepsilon_{m,ref}(t)$$

where:

$\varepsilon_{l,n}(t)$	=	Concrete strain caused by external load to test specimen No. n at the time t [m/m]
$\varepsilon_{m,n}(t)$	=	Strain measured in test specimen No. n at the time t [m/m]
$\varepsilon_{m,ref}(t)$	=	Strain measured in reference specimen at the time t [m/m]. In case of more than one reference specimen the average value is used.

At the time for each loading and off-loading the E-modulus of the concrete is determined by means of linear regression. The initial elastic deformations at the time of loading or off-loading, t' are calculated as:

$$\varepsilon_i(t') = \Delta\sigma(t') \cdot E(t')$$

where:

$\varepsilon_i(t')$ = Initial elastic strain, positive as contraction [m/m]

$\Delta\sigma(t')$ = Change of stress applied at the time t', positive as compression [MPa]

$E(t')$ = E-modulus at the time t' determined by linear regression [MPa]

The creep strain $\varepsilon_{c,n}(t)$ in test specimen No. n is determined as the concrete strain caused by the external load minus the initial elastic strains.

8. Statement of Result

It applies to all graphs that the zero point for time shall correspond to the casting time, unless information to the contrary is stated on the graph.

The same figure can include several graphs.

8.1 Shrinkage

The result is stated as:

Graph with correlated values of maturity and the shrinkage strain of the concrete, $\varepsilon_s(M)$.

Further information:

Age at the start of the measurements given in both decimal hours and maturity rounded off to the next 0.1 hour.

The thermal expansion coefficient used for the concrete and description of how it was determined.

Graph with correlated values of time, concrete temperature and maturity.

Graph with correlated values of time and measured concrete strain, $\varepsilon_{m,n}(t)$.

Graph with correlated values of time and shrinkage strain for each test specimen, $\varepsilon_{s,n}(t)$.

Graph with correlated values of time and shrinkage strain of the concrete, $\varepsilon_{s(t)}$.

8.2 Creep

The result is stated as:

Graph with correlated values of time and creep strain for each test specimen, $\varepsilon_{c,n}(t)$.

Further information:

Age at the start of the measurements given in both decimal hours and maturity rounded off to the next 0.1 hour.

Graph with correlated values of time, concrete temperature and maturity.

Graph with correlated values of time and measured concrete strain, $\varepsilon_{m,n}(t)$.

Graph with correlated values of time and stress applied for each test specimen, $\sigma_n(t)$.

Graph with correlated values of time and concrete strain caused by external load for each test specimen, $\varepsilon_{l,n}(t)$.

Graph with correlated values of time and strain for the reference specimen, $\varepsilon_{m,ref}(t)$. In case more than one reference specimen is used, the correlated values of time and average strain for all reference specimens are also stated.

Table with correlated values of time, maturity and E-modulus determined during the loading and off loading.

Table with correlated values of time and compressive strength.

9. Test Report

A test report shall include at least the following information:

a. Name and address of testing laboratory.
b. Date and identification of the report.
c. Name and address of client.
d. Test method (No. and title).
e. Deviations from the test method, if any.
f. Identification of the concrete.
g. Fresh concrete (slump, air content, temperature, w/c-ratio).
h. Surface defects, if any.
i. Casting date.
j. Starting time for measurements.
k. Test result (refer section 8).
l. Further information of significance for the evaluation of the result.
m. Evaluation of the result, if included in the assignment.
n. Signature.

This annex is included only as a guide and does not form an integral part of the standard.

1. Area of Application

The present annex describes how the shrinkage development proces of concrete determined during and after the hardening process can be described so that the shrinkage is included into a stress calculation of hardening concrete.

It is expected that the annex will be revised as more experience is collected.

The measured shrinkage deformations can be observed by means of tests as described in TI-B 102 "Test Method. Concrete. Strains from Creep and Early-Age Shrinkage".

During the described tests the shrinkage of a concrete specimen without water evaporation is measured as a function of maturity.

2. Scope of Test

The shrinkage development is measured on 3 specimens as described in TI-B 102 "Test Method. Concrete. Strains from Creep and Early-Age Shrinkage".

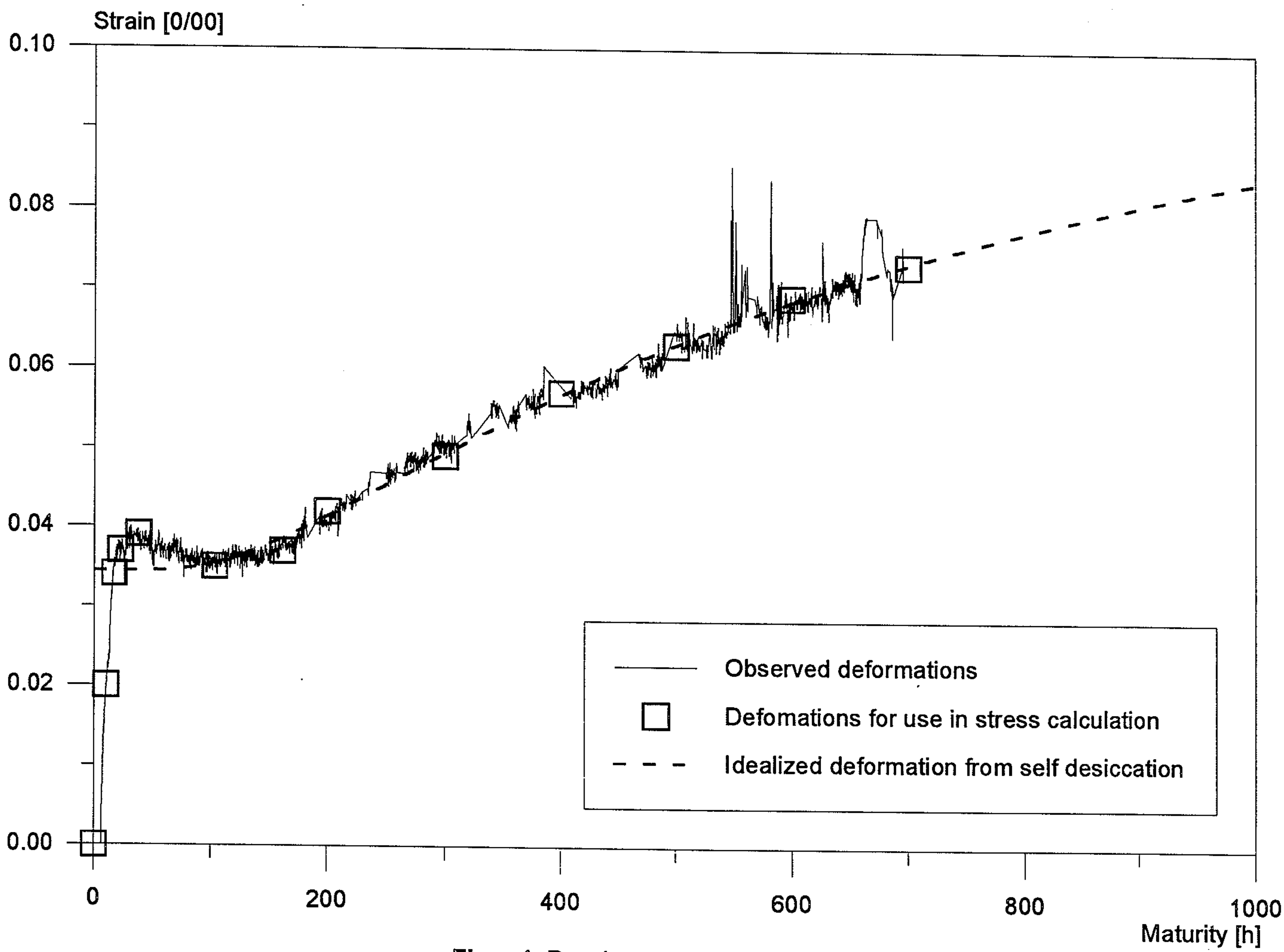
3. Test Results

Figure 1 shows observations from a shrinkage test. The shrinkage strains have been compensated for temperature fluctuations, cf. TI-B 102, by means of a constant thermal expansion coefficient.

For use in calculations of stresses in structures of hardening concrete, the observed deformations as a function of maturity can in principle be used directly. However, originating from the measuring device must be eliminated from the curve which describes the shrinkage development. This can for instance be done by selecting a number of points on the curve, so that the measured development is sufficiently described (figure 1).

The first point of the curve must correspond to the start of the measurement, as described in TI-B 102. Deformations which occur before this time, are assumed not to generate stresses because of the very low E-modulus.

If values of the shrinkage are needed longer than the period of measuring, this can be done in accordance with the theoretical considerations described in section 4.



Figur 1 Development of shrinkage.

4. Theoretical Considerations

The observed deformations can be divided into two groups:

1) When concretes with a low w/c-ratio are involved, the capillary water will be used up as water reacts with cement. This will result in a desiccation shrinkage corresponding to the shrinkage observed by desiccation of non-sealed concretes. Calculations based on w/c-ratios and the heat development curves show that shrinkage originating from self desiccation is observed only after 40 - 100 maturity hours depending on the concrete mix in question.

2) Deformations that are not related to self desiccation shrinkage can be observed in early-age concrete (figure 1). Reference to this type of deformations is found in the literature, but no other explanation is given than it might be a result of chemical shrinkage and/or of a thermal expansion coefficient that varies during the hydration stage.

The self desiccation starts when the capillary water V_k has been used up during the reaction with cement. From Powers phase conversion it is seen:

$$V_k = p - 1.4 (1 - p) \cdot R$$

where p is the specific volume of water before the reaction starts
R is the degree of reaction

The degree of reaction R_{max} corresponding to initial self desiccation is then

$$R_{max} = \frac{p}{1.4 \cdot (1 - p)}$$

The w/c-ratio is introduced by:

$$\frac{p}{1 - p} = \frac{\rho_c}{\rho_v} \cdot v/c \Rightarrow R_{max} = \frac{\rho_c}{\rho_v} \cdot \frac{v/c}{1.4}$$

where ρ_c and ρ_v are the density of cement and water, respectively.

The maturity is introduced by means of the adiabatic thermal development

$$R_{max} = \frac{Q}{Q_\infty} = \exp\left(- \left(\frac{\tau_e}{M} \right)^\alpha \right)$$

where Q_∞, τ_e and α are parameters from the heat development curve of the concrete.

The maturity corresponding to initial self desiccation is then

$$M_{max} = \frac{\tau_e}{(- \ln (2.22 \cdot v/c))1/\alpha}$$

The measured self desiccation shrinkage may be approximated by:

$$\varepsilon_{sd} = (\varepsilon_\infty - \varepsilon_0) \cdot \exp\left(- \left(\frac{\tau}{M} \right)^\alpha \right)$$

where ε_0 = The level corresponding to the zero point of the self desiccation shrinkage

ε_∞ = the level corresponding to total self desiccation

M = maturity

τ, α = curve parameters.

The values of ε_0, ε_∞, τ and α are determined on the basis of the temperature compensated shrinkage strains as a function of maturity (figure 1) by means of the method of least squares. Figure 1 shows the resulting curve. The total self desication shrinkage of the concrete is determined as $\varepsilon_\infty - \varepsilon_0$.

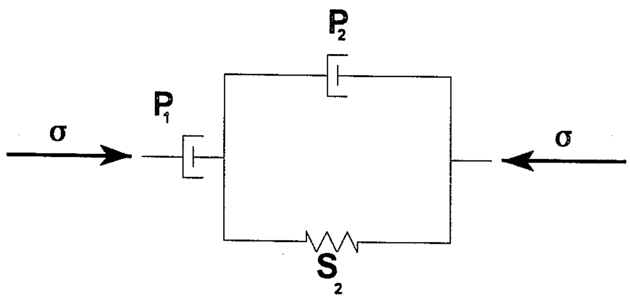
This annex is only included as a guide and does not form an integral part of the standard.

1. Area of Application

TI-B 102 describes the technical aspects of a method for determination of coherent values of load, deformation and time. The present annex describes how the planning of such test and the subsequent data processing may be carried out, when the objective is to establish a mathematical creep model for stress calculations of hardening concrete.

It is expected that the annex will be revised as more experience is collected.

It is assumed that creep deformations of concrete can be described by means of a rheological creep model as shown on figure 1. When a test specimen (see TI-B 102) is exposed to repeated loads and relief of loads, the properties of the viscous pistons and the spring can be determined, including the variation in time.



Figur 1 Rheological model for creep strains.

2. Scope of Test

Test setup and execution of test according to TI-B 102 "Test method. Concrete. Strains from Creep and Early-Age Shrinkage".

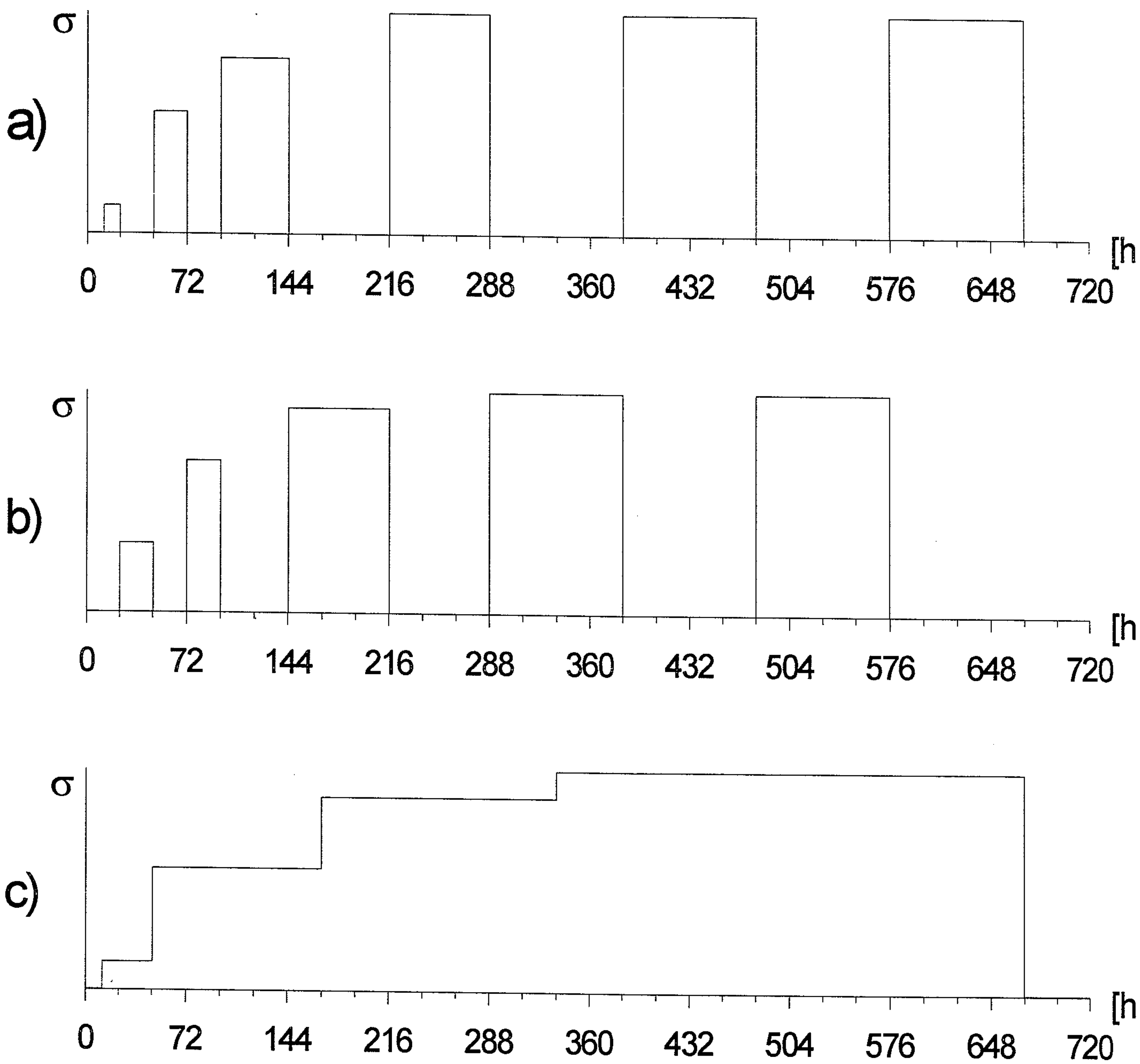
Tests are carried out on 3 test specimens the load periods and load levels are chosen so that 2 of the specimens are continously exposed to load and relief of load. The two specimens shall be exposed to the load and relief of load sequence alternatively - in the beginning rather short load periods and longer load periods as the concrete matures.

The exposure to load and relief of load shall take place alternatively between two specimens.

The third test specimen shall be exposed to load constantly, and the load is increased as the testing procedure progresses.

The maximum load is 40% of the compressive strength and the first load shall take place as early as possible. An example of a load sequence for three test specimens is shown in figure 2.

Moreover, the strains are measured on specimens not exposed to load. These measurements are used to compensate the measurements on the loaded specimens for shrinkage and temperature deformations.



Figur 2 Example of Load sequences.
Load-level = 40% of actual compression strength.
Time = 0: mixing.

The load sequences a) and b) primarily provide information for the determination of the properties of the parallel-coupled units, while load sequence c) provides information about the properties of the outer piston.

3. Processing of Test Results

The deformation measurements as a function of time are compensated in accordance with TI-B 102 for the shrinkage movements and temperature fluctuations of the measuring equipment. Furthermore the creep deformations are isolated from the initial-elastic deformations.

By means of the rheological model the rate of creep strains can be determined by:

$$\dot{\varepsilon} = \frac{\sigma}{\eta_2} - \frac{E}{\eta_2}\varepsilon_2 + \frac{\sigma}{\eta_1}$$

where $\dot{\varepsilon}$ = is the total rate of creep strains
ε_2 = is creep strains in the parallel-coupled units (refer figure 1)
η_1 = is the viscosity of the piston P_1
η_2 = is the viscosity of the piston P_2
E = is the spring constant for the spring S_2

It is assumed that the development of the viscosities and the spring constant can be expressed by:

$$\textit{property} = a \cdot \exp(b \cdot \textit{time})$$

The constants (a and b) of the development of the properties can be determined by the method of least squares performed on all the tests simultaneously.

By means of the development of the concrete temperature measured during the creep test, the creep properties are finally converted into a function of maturity instead of time.

APPENDIX 15

Tests carried out at DTU

HETEK 3+4

Appendix to the report on Phase 6
Testing of Alternative Concrete

Experiments carried out at DTU

Two experiments with the alternative concrete were carried out in equipment at DTU.

- A compression creep experiment at varying temperature 20-40-20 °C.
- A loading on a fixed frame dog-bone specimen

Compression creep 20-40-20 °C

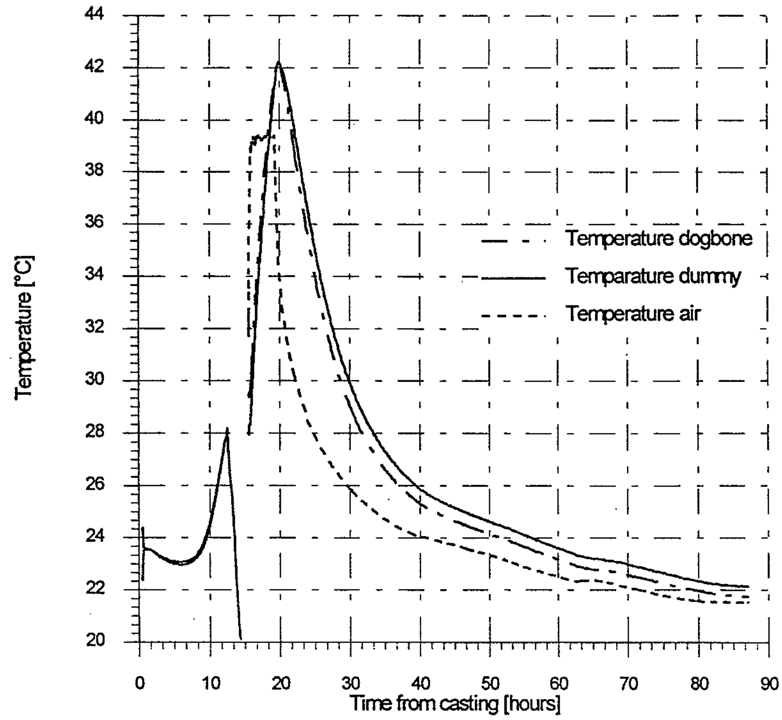
The loading rig and the temperature control hut is described in the report on HETEK 3+4, phase 3, section 2.2.3.

The experiment was carried out in the following way.

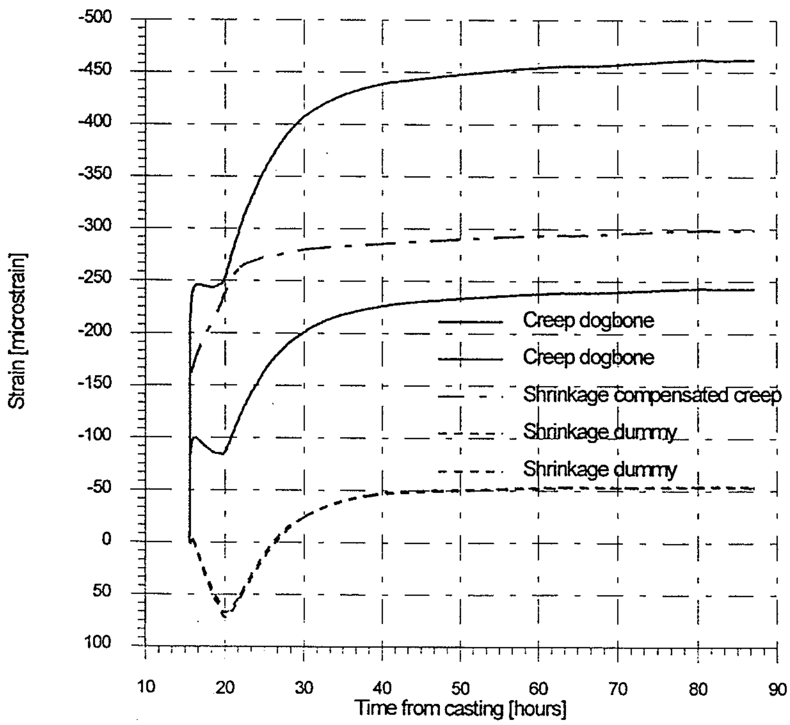
* Mixing and casting at time 0
* The temperature is measured. At 14 hours the temperature in the concrete is maximum and the specimens are demoulded.
* The cylinder, the dummy and the test cylinders are sealed in foil. During this handling the temperature in the concrete drops some degrees.
* Three test cylinders 100×200 mm are tested and the actual strength determined.
* Immediately after the sealing the cylinder is placed in the test frame in the preheated control huts (40 °C) and loaded to 40% of the actual strength.
* 4 hours after the loading the temperature in the concrete has reached 42 °C and the heating in the hut is switched off.
* After 88 hours the experiment is closed down.

The temperature and strain developments are shown in the figures below. (In the legend the word "dogbone" shall be read as "test cylinder").

Temperature vs. time
Load level 40% at 20-40-20°C



Deformation vs. time
Load level 40% at 20-40-20°C



Fixed frame experiment

A fixed frame experiment was carried out as mentioned in the report on HETEK 3+4, phase 4+5, chapter 8.

The dogbone specimen are described in the report on HETEK 3+4, phase 3, section 2.2.1.

The experimental equipment was the same as described in the same report on HETEK 3+4, phase 3, section 2.2.3.

The experiment was carried out in the following way.

* Mixing and casting at time 0 of two dogbone specimens.

* Demoulding of 12 hours, which is just before the temperature in the concrete reaches its maximum.

* One end of the dogbone is glued into a steel cup.

* The dogbone are sealed in foil.

* During these processes the temperature drops some degrees.

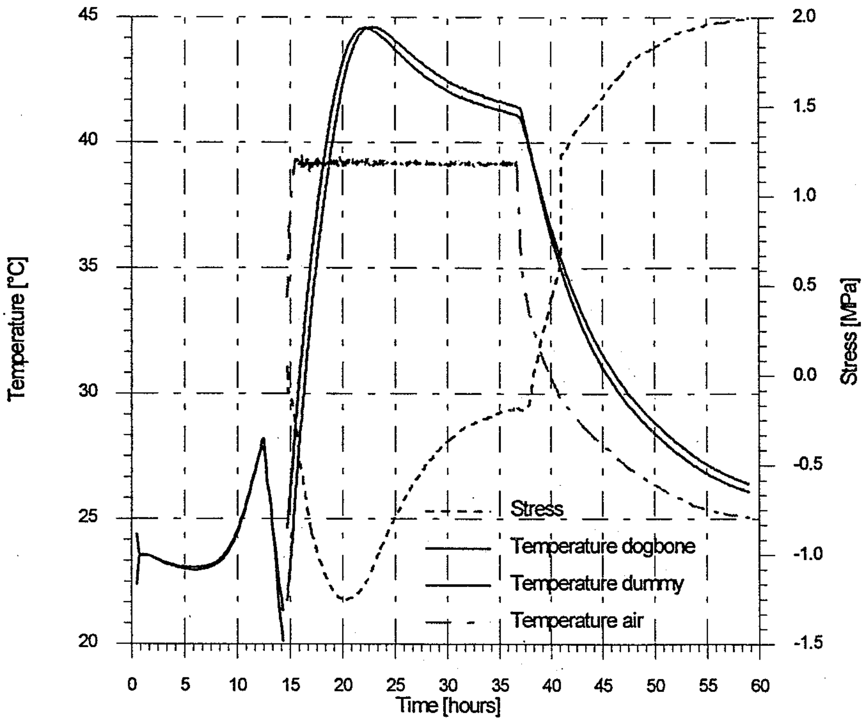
* When the glue is hardened after 30 minutes, the specimen is taken to the pretreated hut. Here it is hanged in the frame in the glued cup. The specimen is lowered down in the bottom cup, so that a small compression is reached. Here the specimen and the cup are glued together.

* The air temperature is kept constant for 22 hours. Hereafter the heating in the hut is switched off.

* After 60 hours the experiment is closed down.

The temperatures, strain and stress developments are shown in the figures below with the heading "relaxation".

Relaxation Alternative concrete



Relaxation Alternative concrete