Project BioCrete

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Final report for Task 6
Technical documentation of bio ash concrete

Performed for:
BioCrete

Performed by:
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Title: Technical documentation of bio ash concrete

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Content

1. Preface

“BioCrete” is the acronym for a LIFE supported project ”Utilisation of ash from incineration of wastewater sludge (bio ash) in concrete production”. The project activities have been defined in 10 tasks, and the present report is the final report for one task, summarising purpose, task progress, results and experiences. The report is written by the task coordinator, as identified by initials for participant and name. The project period is June 2005 to December 2007, and the project includes 4 participants: Avedoere Wastewater Services (AWS) as beneficiary, Lynettefaellesskabet (LYNIS) and Unicon Ltd. (UNICON) as partners and Danish Technological Institute (DTI) as consultants.

2. Introduction

In terms of traditional concrete technology a few concerns have been raised in connection with the use of bio ash concrete. For this reason, in Denmark, bio ash is only allowed to be used in concrete for passive environment. To use bio ash concrete in other more aggressive environmental classes more documentation is required primarily on long-term durability and strength development, in particular the role played by the high content of P_2O_5 in the bio ash. Consequently, the task will attempt to clarify the above issues and by performing a suite of tests that will provide better knowledge of the long-term durability and strength development of bio ash concrete.

2.1. Long-term durability

The long-term durability of bio ash concrete will be documented through accelerated performance testing, and through microscopic analysis of the bio ash concrete. Two bio ash concretes (AWS ash, LYNIS ash) and a reference concrete will be tested for each of the three environmental classes passive, moderate and aggressive. The following test methods will be performed:

- Freeze-thaw resistance (SS 13724 and EN 480-11)
- Cl-ion penetration (NT BUILD 492)
- Shrinkage (DS 434.6)
- Microstructure characterization (TI-B5)

The first two test apply only to concrete in moderate and aggressive environment classes, whereas the last two test will be carried out on concrete in both passive (P), moderate (M) and aggressive (A) environment classes.

2.2. Strength development

The influence on strength development (including setting time, Task 4) will be investigated for a suite of six selected bio ashes (three from each of LYNIS WWTP and AWS WWTP). The ashes investigated will be selected based on their total P_2O_5 content as well as their soluble P_2O_5 content (soluble phosphate is strongly retarding the setting of concrete). The P_2O_5 parameters are available from Task 4. Two bio ash concretes will be tested in the passive and aggressive environmental class, respectively. The following tests will be performed:

- Setting time EN 196-3 (Task 4)
- Heat development of concrete through semi-adiabatic Hay-box calorimetry (NT BUILD 388:1992)
- Compressive strength development of bio ash concretes. Strength measured at 2, 7, 28 and 56 days according to EN 12390-1, 2, 3, 4.

3. Task progress

The mix design for the different environmental classes was changed from using 100% replacement of normal coal fly ash with bio ash to using 50% bio ash and 50% coal fly ash. The reason for changing the mix was that preliminary tests had shown lower strength and difficulties with the fresh properties of the concrete mixes. Furthermore, the bio ash from LYNIS was too coarse to be used without further treatment, so this ash was milled to a finer particle size distribution.

All the tests described above were performed as planned except Cl-ion penetration and micro structure characterization since these test were performed in Task 7.

4. Results

In the following the outcome of the tests are described. For further information regarding the results - see the appendices.

4.1. Long-term durability

- Freeze-thaw resistance (class M and A)

The results from all tested concrete mixes except M30 Lynis-1 were “very good”, the result from M30 Lynis-1 was “good”. Overall all the tested concrete mixes performed well with only small variations between the results of the different ashes and concrete types. The general trend was that the reference fly ash performed slightly better than AWS-1, and that AWS-1 performed slightly better than Lynis-1. The requirement in DS/EN 206-1 and DS 2426 is “good”. The results from the freeze-thaw testing are available in appendix 4.

- Shrinkage (class P, M and A)

In general the measured values of shrinkage for all tested samples are normal for concrete of these mix designs and conditions. The first measurement of the A35 Reference was performed after four days, compared to one day for the rest of the samples, this has been taken into account in the evaluation of the shrinkage data.

The following conclusions can be made from the shrinkage measurements:

There is no significant difference in shrinkage between AWS-1 and Lynis-1 (The shrinkage of AWS-1 is larger than that of Lynis-1 in the A35 concrete, but this is not the case in the P20 and M30 concretes).

The Bio ashes show a slightly larger shrinkage than the reference concrete mix, this is more pronounced in the P20 and M30 concrete mixes, and less so for the A35 concrete mix.

4.2. Heat and strength development

- Heat development and setting time of concrete through semi-adiabatic Hay-box calorimetry (NT BUILD 388:1992)

The results from the heat development tests are available in appendix 5. A summary of the results are presented in table 1 together with values from typical Danish reference concretes with fly ash.

In general the results from the heat development tests are normal for these mix designs and conditions, though there are a few differences from the typical values. For the A35 Concrete mixes the value for Tau_e are higher than the typical values, this is the case for both the AWS and Lynis ashes. For the P20 concrete mixes only the Lynis ash shows a higher value for Tau_e than the typical value. The Tau_e value correlates to the setting time of the concrete and a higher value indicates a longer setting time. In general the values for Tau_e shows similar results regarding the relative setting time between the different bio ashes, compared to the actual setting time from Task 4. No connection between the indicated setting time from the value of Tau_e and the content of phosphate in the bio ash has been found. For both the AWS and the Lynis ashes the value for alpha is slightly higher than the typical value. This indicates a more rapid heat development once the concrete has started to set. There is no significant difference on the alpha value between the AWS and Lynis ashes.

	Q (kJ/kg)			
Concrete mix	Cement	Cement+Ash	Tau_e (h)	alpha
A35 AWS-1	343,7	281,7	20,51	1,43
A35 AWS-2	380	311,5	28,5	1,56
A35 AWS-3	360,8	295,7	24,54	1,5
A35 Lynis-1	373,9	306,4	25,53	1,38
A35 Lynis-2	343,6	281,6	30,39	1,81
A35 Lynis-3	407,4	333,9	25,81	1,28
P20 AWS-1	395,4	298	20,38	0,94
P20 AWS-2	407	306,8	18,93	0,98
P20 AWS-3	332,9	250,9	16,99	1,18
P20 Lynis-1	393,9	296,9	25,18	1,01
P20 Lynis-2	417,5	314,7	24,2	0,98
P20 Lynis-3	415,2	313	23,99	0,97
Typical A35	355	287	17,4	1,16
Typical P20	442	297	19,9	0,91

Table 1. Results from semi-adiabatic calorimetry

- Compressive strength development of bio ash concretes. Strength measured at 2, 7, 28 and 56 days according to EN 12390-1, 2, 3, 4.

After the casting of the compressive strength samples it was discovered that the pressure meter used for the air content measurement during the casting of the compressive strength samples was malfunctioning, because of this the measured air content in the fresh concrete can not be used in the evaluation of the compressive strength results.

The actual air content of the different concrete mixes has been calculated from the measured cylinder densities. Furthermore the air content for two samples has been analysed according to ASTM C 457 in order to validate the calculated air content.

After evaluating the measured compressive strengths together with the actual air content of the concrete mixes the following conclusions can be made regarding the compressive strength of the concrete mixes:

For the mix designs used in this task, there is no significant difference in compressive strength between the Bio Ashes and the Reference. (Although the extreme air content of the Reference makes it difficult to evaluate the compressive strength for this particular concrete mix). There is also no difference between the compressive strength development between the different bio ashes.

There is no significant difference in compressive strength between the used batches of AWS ash. (The compressive strength of AWS-1 is lower than that of AWS-2 and AWS-3 in the P20 concrete, but this is not the case in the A35 concrete. The extreme air content of the concrete with AWS-1 makes it difficult to evaluate the compressive strength for this particular mix)

For the mix design used in this task, there is no significant difference in compressive strength between the used batches of Lynis ash.

5. Conclusion

In this task the durability and strength development of a total of 6 samples of bio ash has been evaluated, 3 samples each from Avedøre (AWS) and Lynetten (Lynis).

There were only minor variations in the results from the freeze-thaw tests between the different ashes including the reference. All samples fulfilled the requirements of DS-EN 206-1 and DS2426.

The effect of the different bio ashes on the shrinkage of concrete was evaluated according to the principles in DS 434.6. In general there were very small differences between the results of the different concrete samples including the reference, although the shrinkage of the concrete samples cast with bio ash was slightly higher than that of the reference.

The heat development measurements have been performed through semi-adiabatic Hay-box calorimetry. The total heat development of the bio ash concrete mixes is comparable to that of typical reference concrete mixes with fly ash. The heat development measurements indicate that the setting time for the bio ash concrete mixes are higher than that of concrete mixes with fly ash, but once the setting starts the heat development is slightly more rapid.

In general the compressive strength measurements showed no significant differences between the different bio ashes and the reference.

Overall the concrete mixes had similar properties regarding durability and strength development, with the only major difference being the later setting time indicated in the heat development test. It was possible to obtain satisfactory fresh concrete properties with both types of bio ash, although the mix designs had to be modified to compensate for the bio ashes higher water demand. All concrete mixes were modified with higher paste content and/or higher super plasticizer dosage and a 50-50 percent mix of fly ash and bio ash, in order to obtain satisfactory fresh concrete properties.

6. Appendices

A. Concrete mixes and used ashes
B. Fresh concrete results (slump air etc.)
C. Results regarding durability: shrinkage
D. Results regarding durability: freeze-thaw resistance.
E. Results regarding heat development of bio ash concretes.
F. Results regarding strength development.

Appendix A

Concrete mixes and used ashes

Ashes

The ashes investigated in this task have been selected based on their total P_2O_5 content as well as their soluble P_2O_5 content. The P_2O_5 data are available in Task 4.

Used Ashes		P_2O_5 Content	
Task 6	Markings	Soluble (mg/kg)	Total (%)
AWS 1	Avedøre 6/10	92	26
AWS 2	Avedøre 21/8	29	22
AWS 3	Avedøre 19/6	73	27
Lynis 1	Lynis 26/7	24	26
Lynis 2	Lynis 1/9	22	23
Lynis 3	Lynis 15/11		23

Table 1. Bio ashes used in task 6.

Concrete mixes

The investigated concrete mixes are based on reference mixes from Unicon Ltd. The preliminary tests with the reference mix designs and the various bio ashes indicated that the water demand of the concrete mixes increased when fly ash was replaced with bio ash. The Lynis ashes increased the water demand more than the AWS ashes. Based on these test it was decided that the concrete mixes used in this task should use a 50-50 percent mix of reference coal fly ash (Avedøre B4) and bio ash. The concrete mix designs were also modified based on the bio ashes influence on the water demand of the concrete mixes. The used concrete mixes are listed in the tables 2 – 4 below.

Parameter	**Unit**	**Concrete Mix**		
		A35 Ref	A35 AWS (1-3)	A35 Lynis (1-3)
Mix design (recipe)				
Cement(C)	kg/m^3	323,8	336,3	348
Fly ash	kg/m^3	64,9	37	38,3
Bio ash	kg/m^3		37,1	38,3
Water(W)	kg/m^3	149,5	155,2	160,6
Air (target)	% vol.	6,5	6,5	6,5
Fine aggregate	kg/m^3	778	751,5	737,4
Coarse aggregate	kg/m^3	970,8	930,4	912,9
W/C eq (k = 0.5 for ash)	kg/kg	0,42	0,42	0,42

Table 2. A35 Concrete mixes.

Parameter	Unit	Concrete Mix		
		M30 Ref	M30 AWS 1	M30 Lynis 1
Mix design (recipe)				
Cement(C)	kg/m^3	260	266,6	276,1
Fly ash	kg/m^3	78	43,8	45,4
Bio ash	kg/m^3		44	45,6
Water(W)	kg/m^3	146,4	150,1	155,5
Air (target)	% vol.	6	6	6
Fine aggregate	kg/m^3	805,6	776,8	765,5
Coarse aggregate	kg/m^3	982,4	961,7	947,8
W/C eq (k = 0.5 for ash)	kg/kg	0,49	0,49	0,49

Table 3. M30 Concrete mixes.

Parameter	Unit	Concrete Mix		
		P20 Ref	P20 AWS (1-3)	P20 Lynis (1-3)
Mix design (recipe)				
Cement(C)	kg/m^3	201,6	211,6	211,6
Fly ash	kg/m^3	59,9	34,5	34,5
Bio ash	kg/m^3		34,6	34,6
Water(W)	kg/m^3	155	162,7	162,7
Air (target)	% vol.	4,3	4,3	4,3
Fine aggregate	kg/m^3	847,1	829,7	829,7
Coarse aggregate	kg/m^3	974,1	954,1	954,1
W/C eq (k = 0.5 for ash)	kg/kg	0,67	0,67	0,67

Table 4. P20 Concrete mixes.

The admixture dosage was also investigated in the preliminary testing and a base dosage was set for each concrete mix. In order for each concrete mix to have the specified workability and air content, the actual dosage was modified during the mixing of the final concrete mixes. The target slump for all concrete mixes was 150mm, and the target air content was 4,5% for P20 mixes, 6,0% for M30 mixes and 6,5% for A35 mixes. The actual admixture dosages for all concrete mixes are given in table 5.

	Admixture dosage (by weight of powder)		
Concrete mix	Plasticizer	Super Plasticizer	Air Entrainer
A35 AWS 1	0,55%	0,25%	0,15%
A35 AWS 2	1,06%	0,38%	0,24%
A35 AWS 3	0,69%	0,42%	0,25%
A35 Lynis 1	0,75%	0,38%	0,38%
A35 Lynis 2	0,80%	0,40%	0,30%
A35 Lynis 3	0,75%	0,50%	0,20%
A35 Ref	0,90%	0,38%	0,25%
M30 AWS 1	0,90%	0,40%	0,20%
M30 Lynis 1	1,00%	0,47%	0,75%
M30 Ref	0,90%	0,16%	0,30%
P20 AWS 1	0,60%	0,30%	0,50%
P20 AWS 2	0,60%	0,30%	0,40%
P20 AWS 3	0,60%	0,30%	0,45%
P20 Lynis 1	0,70%	0,40%	1,20%
P20 Lynis 2	0,70%	0,40%	1,10%
P20 Lynis 3	0,70%	0,40%	1,30%
P20 Ref	0,55%	0,24%	0,51%

Table 5. Admixture dosage.

Appendix B

Fresh concrete test results.

The fresh properties of the concrete mixes were measured during the casting of the test specimens. Initial slump as well as slump after 30 and 60 minutes, air content, fresh density and temperature was measured. Due to a malfunction of the pressure meter used during the testing, the actual air content was considerably higher in the concrete mixes than the measurement given by the pressure meter. The actual air content of the different concrete mixes has been calculated from the measured cylinder densities. Furthermore the air content for two samples has been analysed according to ASTM C 457 in order to validate the calculated air content.

	Slump (mm)				
Concrete mix	After mixing	After 30 min	After 1h	Density (kg/m3)	Temperature (°C)
A35 AWS 1	140	90	50	2133	21,1
A35 AWS 2	160	120		2231	23,9
A35 AWS 3	185	150	130	2133	21
A35 Lynis 1	155	100		2219	20,8
A35 Lynis 2	200	170	130	2173	23,1
A35 Lynis 3	160	160	130	2210	23
A35 Ref	190			2183	21,5
M30 AWS 1	140	80		2166	21
M30 Lynis 1	120	60	30	2219	20
M30 Ref	180	120		2149	21
P20 AWS 1	160	160	160	2018	20,8
P20 AWS 2	170	160		2095	20,2
P20 AWS 3	200	190	155	2104	21,1
P20 Lynis 1	160	150		2100	20,4
P20 Lynis 2	180	150	100	2111	23,7
P20 Lynis 3	160	150	120	2094	19,7
P20 Ref	135	120		2173	21,5

Table 1. Fresh concrete properties.

	Air Content		
Concrete mix	Pressure Meter	Cylinder density	ASTM C457
A35 AWS 1	4,8%	11,3%	
A35 AWS 2	3,9%	9,0%	
A35 AWS 3	5,1%	11,1%	
A35 Lynis 1	3,9%	7,9%	8,0%
A35 Lynis 2	4,4%	8,9%	
A35 Lynis 3	4,2%	8,0%	
A35 Ref	4,6%	14,3%	
M30 AWS 1	5,2%		
M30 Lynis 1	5,3%		
M30 Ref	5,4%		
P20 AWS 1	5,2%	14,6%	13,7%
P20 AWS 2	4,7%	10,4%	
P20 AWS 3	4,7%	11,0%	
P20 Lynis 1	4,4%	11,7%	
P20 Lynis 2	4,5%	9,6%	
P20 Lynis 3	4,5%	10,2%	
P20 Ref	4,8%		

Table 2. Comparison of air content from pressure meter, cylinder density and ASTM C457.

Appendix C

Shrinkage measurements

Shrinkage measurements were performed with the ashes AWS-1, Lynis-1 and the reference ash on all three concrete types. The results from the measurements are given in table 1.

Age	Shrinkage (o/oo)								
(days)	A35 REF	A35 Lynis-1	A35 AWS-1	M30 REF	M30 Lynis-1	M30 AWS-1	P20 REF	P20 Lynis-1	P20 AWS-1
1		0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
2		0,036		0,049	0,081	0,071	0,010	0,019	0,054
4	0,000								
5		0,063	0,097						
6		0,103							
7	0,048	0,108	0,121	0,135	0,168	0,158	0,039	0,069	0,111
14	0,186	0,211	0,222	0,214			0,097	0,177	0,253
15					0,253	0,271			
21		0,277	0,281	0,274	0,301	0,293	0,174	0,283	0,281
28	0,256	0,314	0,342	0,303	0,334	0,337	0,240	0,322	0,310
56	0,328	0,382	0,432	0,351	0,381	0,372	0,325	0,397	0,378

Table 1. Results from the shrinkage measurements.

The first measurement of the A35 Reference was performed after four days, compared to one day for the rest of the samples, this has been taken into account in the evaluation of the shrinkage data. Plots of the shrinkage versus age are available in diagrams 1 – 3.

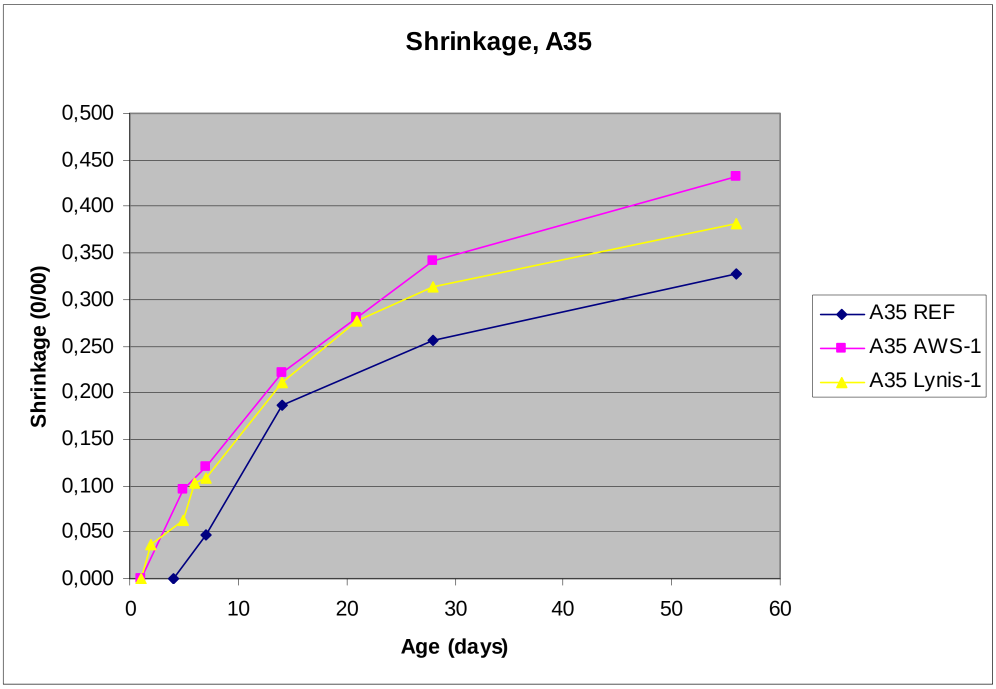

Diagram 1. Shrinkage, A35

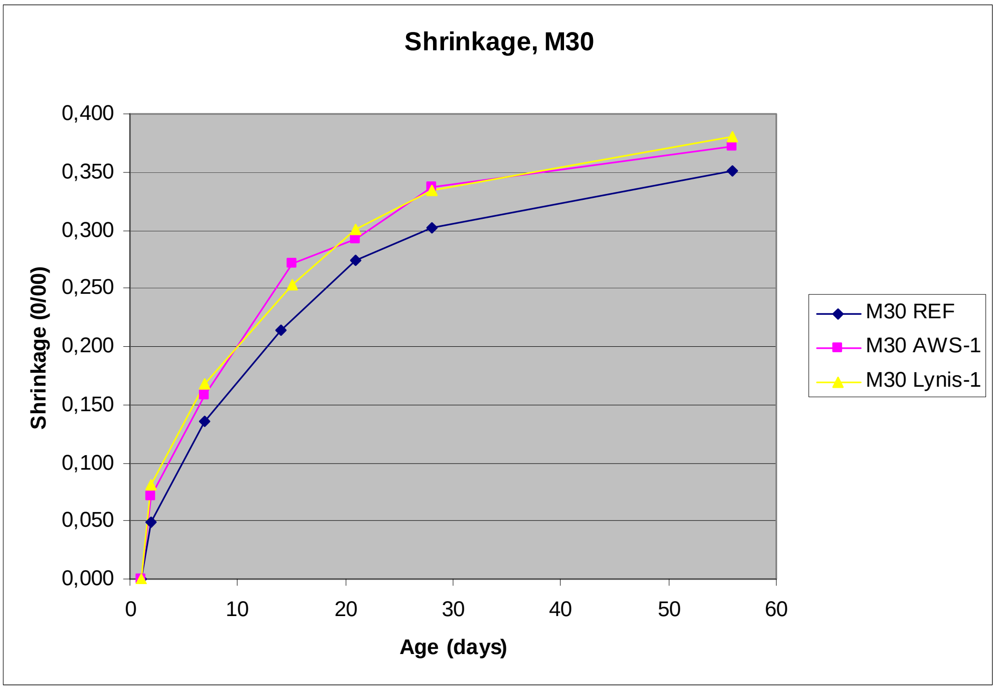

Diagram 2. Shrinkage, M30

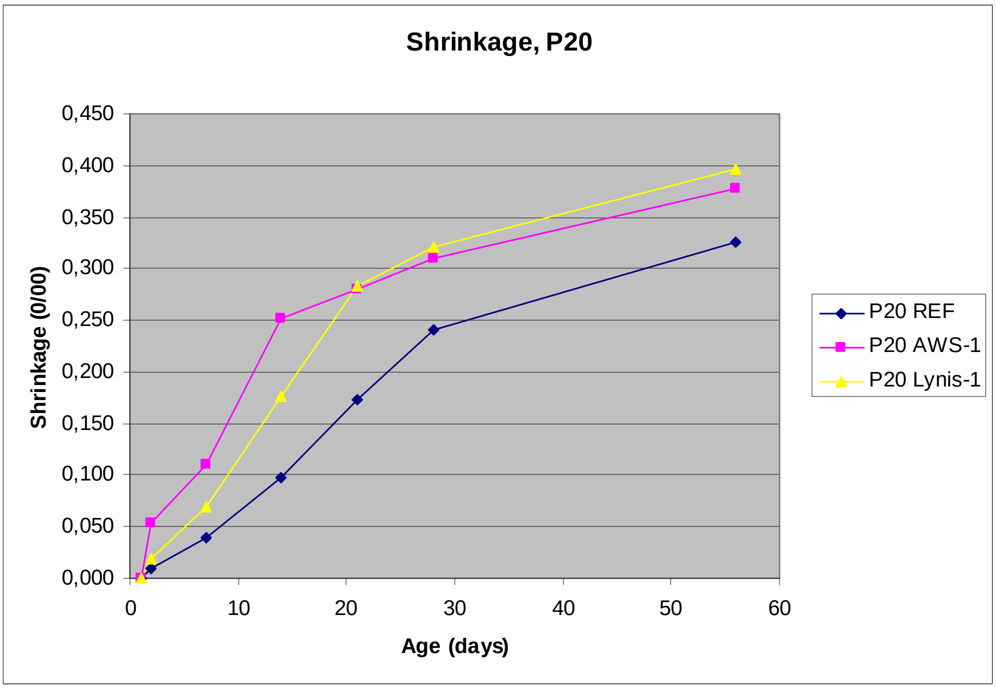

Diagram 3. Shrinkage, P20

Appendix D

Results regarding durability: freeze thaw.
Test report: SS 137244 A III (1995): Betongprovning – Hårdnad betong – Avflagning vid frysning.

DANAK
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Prøvningsrapport

Materiale:	24 stk. betoncylindre Ø 150 mm. Vedrørende, BioCrete.
Udtagning:	Prøvematerialet er udstøbt på Teknologisk Institut. Mærkningen fremgår af efterfølgende side.
Metoder:	SS 13 72 44 A III (1995): Betongprovning – Hårdnad betong – Avflagning vid frysning.
Periode:	Emnerne blev prøvet i perioden fra 2007-03-14 til 2007-08-24.
Resultater:	Resultaterne fremgår af side 2 og 3.

Vilkår: Prøvningen er udført på omstående vilkår i henhold til de for laboratoriet af DANAK (Dansk Akkreditering) fastsatte retningslinier herfor. Prøvningen gælder kun for det prøvede materiale. Prøvningsrapporten må kun gengives i uddrag, hvis laboratoriet har godkendt uddraget.

2007-08-30, Teknologisk Institut, Beton, Taastrup.

Tine Aarre
Laboratorieleder, Ph.D.
Direkte telefon 72 20 21 61

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Frostprøvning efter SS 13 72 44 A III

Prøvning - start: 2007-04-27
Prøvning - slut: 2007-06-22

Prøve ID	Fryseareal	Afskallet materiale total (kg/m^2)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
M30 Lynis-1, 1	15792	0,06	0,10	0,11	0,11	0,11	1,0
M30 Lynis-1, 2	16764	0,10	0,13	0,15	0,16	0,16	1,1
M30 Lynis-1, 3	16399	0,12	0,16	0,18	0,18	0,18	1,0
M30 Lynis-1, 4	16490	0,06	0,09	0,11	0,11	0,11	1,0
Middelværdi		0,09	0,12	0,14	0,14	0,14	1,0

Prøvning - start: 2007-04-13
Prøvning - slut: 2007-06-08

Prøve ID	Fryseareal	Afskallet materiale total (kg/m^2)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
A35 Lynis-1, 1	16673	0,02	0,04	0,04	0,05	0,05	1,2
A35 Lynis-1, 2	15948	0,02	0,05	0,05	0,06	0,06	1,2
A35 Lynis-1, 3	16559	0,02	0,03	0,03	0,04	0,04	1,2
A35 Lynis-1, 4	16467	0,02	0,04	0,04	0,05	0,05	1,1
Middelværdi		0,02	0,04	0,04	0,05	0,05	1,2

Prøvning - start: 2007-04-13
Prøvning - slut: 2007-06-08

Prøve ID	Fryseareal	Afskallet materiale total (kg/m^2)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
A35 AWS-1, 1	16604	0,01	0,01	0,02	0,02	0,02	1,4
A35 AWS-1, 2	16377	0,00	0,01	0,01	0,01	0,02	1,4
A35 AWS-1, 3	16810	0,00	0,01	0,01	0,02	0,02	1,4
A35 AWS-1, 4	16309	0,01	0,01	0,02	0,02	0,02	1,3
Middelværdi		0,01	0,01	0,02	0,02	0,02	1,4

Frostprøvning efter SS 13 72 44 A III

Prøvning - start: 2007-06-15
Prøvning - slut: 2007-08-24

Prøve ID	Fryseareal	Afskallet materiale total (kg/m²)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
M30 AWS-1, 1	15859	0,03	0,04	0,06	0,07	0,09	1,5
M30 AWS-1, 2	15197	0,01	0,02	0,04	0,05	0,06	1,6
M30 AWS-1, 3	15570	0,03	0,04	0,06	0,06	0,07	1,3
M30 AWS-1, 4	15637	0,05	0,06	0,06	0,06	0,07	1,2
Middelværdi		0,03	0,04	0,05	0,06	0,07	1,4

Prøvning - start: 2007-06-15
Prøvning - slut: 2007-08-24

Prøve ID	Fryseareal	Afskallet materiale total (kg/m²)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
M30 Ref-1,1	15416	0,02	0,02	0,03	0,03	0,04	1,5
M30 Ref-1,2	15460	0,01	0,02	0,03	0,06	0,07	2,3
M30 Ref-1,3	15659	0,01	0,01	0,01	0,02	0,02	1,4
M30 Ref-1,4	15904	0,02	0,02	0,03	0,04	0,05	1,3
Middelværdi		0,01	0,02	0,03	0,04	0,04	1,6

Prøvning - start: 2007-06-11
Prøvning - slut: 2007-08-20

Prøve ID	Fryseareal	Afskallet materiale total (kg/m²)					m_{56}/m_{28}
		m_7	m_{14}	m_{28}	m_{42}	m_{56}	
A35- Ref, 1	15615	0,00	0,00	0,01	0,01	0,01	2,6
A35- Ref, 2	16083	0,00	0,01	0,01	0,01	0,02	2,1
A35- Ref, 3	15703	0,00	0,00	0,00	0,00	0,01	1,7
A35- Ref, 4	15659	0,00	0,00	0,00	0,01	0,01	3,0
Middelværdi		0,00	0,00	0,01	0,01	0,01	2,4

Teknologisk Instituts almindelige vilkår for rekvirerede opgaver gælder i deres fulde udstrækning for den ved Teknologisk Institut udførte tekniske prøvning og kalibrering samt for udfærdigelsen af prøvningsrapporter hhv. kalibreringscertifikater i forbindelse hermed.

Dansk Akkreditering (DANAK)

DANAK blev etableret i 1991 med hjemmel i lov nr. 394 om erhvervsfremme af 13. juni 1990.

Kravene til akkrediterede prøvningslaboratorier er fastlagt i Erhvervsfremme Styrelsens bekendtgørelse om akkreditering af laboratorier til teknisk prøvning m.v., samt til GLP-inspektion. Bekendtgørelsen henviser til andre dokumenter, hvor akkrediteringskriterierne er beskrevet yderligere.

Standarderne DS/EN ISO/IEC 17025 “Generelle krav til prøvnings- og kalibreringslaboratoriers kompetence” og DS/EN 45002 “Generelle kriterier for bedømmelse af prøvningslaboratorier” beskriver grundlæggende akkrediteringskriterier. DANAK anvender fortolkningsdokumenter til de enkelte krav i standarderne, hvor det skønnes nødvendigt. Disse vil hovedsageligt være udarbejdet af ”European co-operation of Accreditation (EA)” eller ”International Laboratory Accreditation Co-operation (ILAC)” med det formål at opnå ensartede kriterier for akkreditering på verdensplan. DANAK udarbejder desuden tekniske forskrifter vedr. specifikke krav til akkreditering, som ikke er indeholdt i standarderne.

For at et laboratorium kan være akkrediteret kræves blandt andet:

- at laboratoriet og dets personale skal være fri for enhver kommerciel, økonomisk eller anden form for pression, som kan påvirke deres tekniske dømmekraft.

- at laboratoriet har et dokumenteret kvalitetsstyringssystem.

- at laboratoriet råder over teknisk udstyr og lokaler af en tilstrækkelig standard til at kunne udføre den prøvning, som laboratoriet er akkrediteret til.

- at laboratorieledelse og -personale har såvel faglig kompetence som praktisk erfaring i udførelsen af den ydelse, som laboratoriet er akkrediteret til.

- at der er indarbejdet faste rutiner for sporbarhed og usikkerhedsbestemmelse.

- at akkrediteret prøvning eller kalibrering udføres efter fuldt validerede og dokumenterede metoder.

- at laboratoriet skal registrere forløbet af akkrediteret prøvning eller kalibrering således, at dette kan rekonstrueres.

- at laboratoriet er underkastet regelmæssigt tilsyn af DANAK.

- at laboratoriet skal have en forsikring, som kan dække laboratoriets ansvar i forbindelse med udførelsen af akkrediterede ydelser.

Rapporter, der bærer DANAK’s logo, anvendes ved rapportering af akkrediterede ydelser og viser, at disse er foretaget i henhold til akkrediteringsreglerne.

Appendix E

Results regarding heat development of bio ash concretes.
Test report: NT Build 388: 1992, Heat development. Haybox calorimeter.

DANAK
Reg. nr. 11

TEKNOLOGISK
INSTITUT

Gregersensvej
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Teknologisk Institut
Byggeri, Beton

Rapport nr.	197644-1
Side	1 af 2
Antal bilag	13
Initialer	FOE

Prøvningsrapport

Materiale:	12 betonprøver i 5 liter prøvespande. Vedrørende, BioCrete.
Udtagning:	Prøvematerialet er udstøbt af Teknologisk Institut.
Metode:	NT Build 388: 1992, Heat Development. Haybox calorimeter.
Periode:	Prøvningen er gennemført i perioden marts – juni 2007
Resultater:	Resultaterne fremgår af side 2.

Vilkår: Prøvningen er udført på omstående vilkår i henhold til de for laboratoriet af DANAK (Dansk Akkreditering) fastsatte retningslinier herfor. Prøvningen gælder kun for det prøvede materiale. Prøvningsrapporten må kun gengives i uddrag, hvis laboratoriet har godkendt uddraget

---

2007-09-04, Teknologisk Institut, Beton, Taastrup

Jens Ole Frederiksen
Civilingeniør
Direkte telefon: 72 20 22 18

Finn Østergård
Laborant
Direkte telefon: 72 20 21 67

990756_2007 197644 BioCrete.doc

Varmeudviklingsparametre:

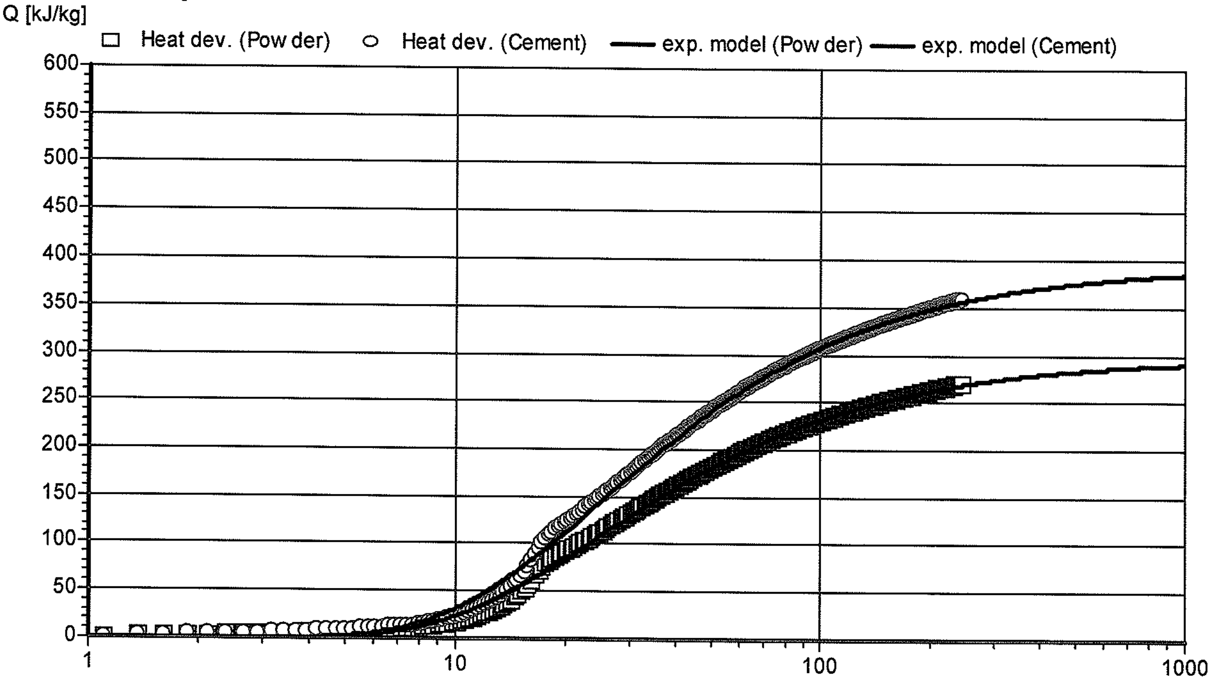
	Q_∞	τ_e	α
P20 Lynis-1. Cement	393,9 kJ/kg	25,18 hours	1,01
P20 Lynis-1. Cement + aske	296,9 kJ/kg		
P20 Lynis-2. Cement	417,5 kJ/kg	24,20 hours	0,98
P20 Lynis-2. Cement + aske	314,7 kJ/kg		
P20 Lynis-3. Cement	415,2 kJ/kg	23,99 hours	0,97
P20 Lynis-3. Cement + aske	313,0 kJ/kg		
P20 AWS-1. Cement	395,4 kJ/kg	20,38 hours	0,94
P20 AWS-1. Cement + aske	298,0 kJ/kg		
P20 AWS-2. Cement	407,0 kJ/kg	18,93 hours	0,98
P20 AWS-2. Cement + aske	306,8 kJ/kg		
P20 AWS-3. Cement	332,9 kJ/kg	16,99 hours	1,18
P20 AWS-3. Cement + aske	250,9 kJ/kg		
A35 Lynis-1. Cement	373,9 kJ/kg	25,53 hours	1,38
A35 Lynis-1. Cement + aske	306,4 kJ/kg		
A35 Lynis-2. Cement	343,6 kJ/kg	30,39 hours	1,81
A35 Lynis-2. Cement + aske	281,6 kJ/kg		
A35 Lynis-3. Cement	407,4 kJ/kg	25,81 hours	1,28
A35 Lynis-3. Cement + aske	333,9 kJ/kg		
A35 AWS-1. Cement	343,7 kJ/kg	20,51 hours	1,43
A35 AWS-1. Cement + aske	281,7 kJ/kg		
A35 AWS-2. Cement	380,0 kJ/kg	28,58 hours	1,56
A35 AWS-2. Cement + aske	311,5 kJ/kg		
A35 AWS-3. Cement	360,8 kJ/kg	24,54 hours	1,50
A35 AWS-3. Cement + aske	295,7 kJ/kg		

De øvrige oplysninger om varmeudviklingen fremgår af bilag 1- 12.

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 LYNIS1.prj Printed: 31-08-2007 09:09:52

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	393,9	25,18	1,01	146,1	9,34
Total powder:	296,9	25,18	1,01	110,1	9,34

Concrete

Concrete Id: P20 Lynis-1.

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2100	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,0076 kg Mixing time: 12-03-2007 12:25:00 Mixing temp.: 20,4 °C

Haybox

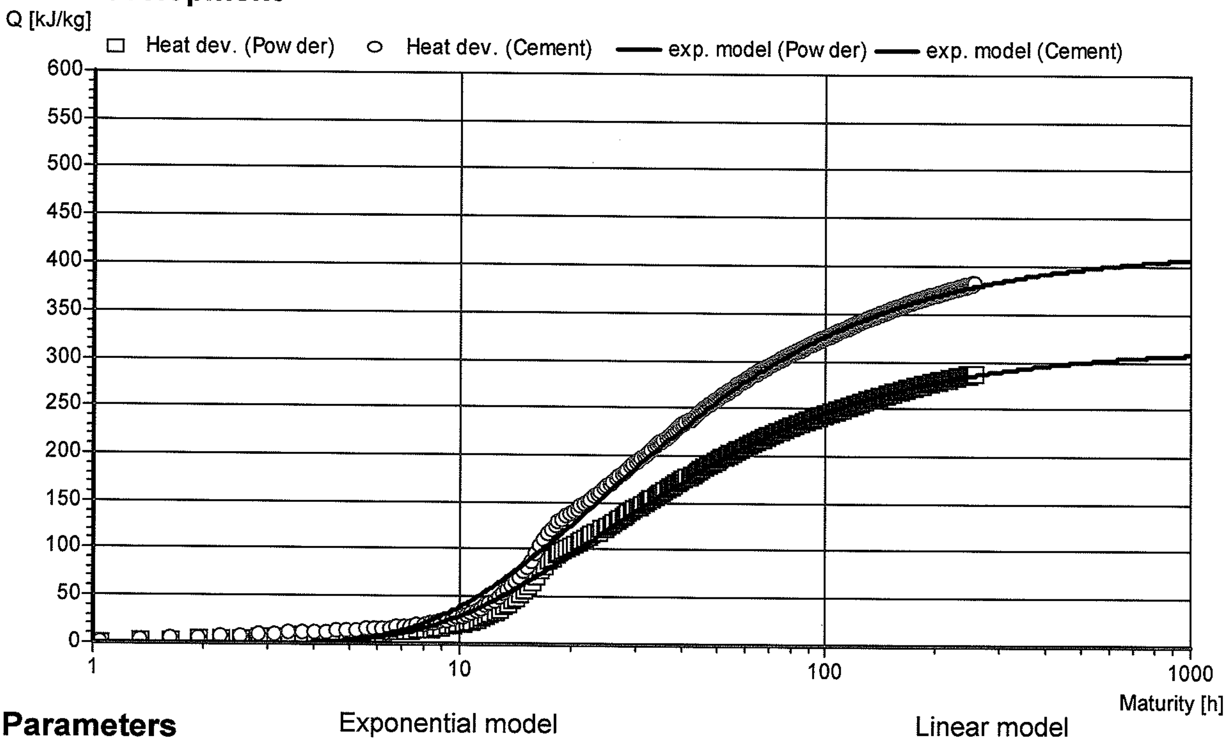
Haybox Id: Høkasse nr. 5

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 LYNIS2.prj Printed: 31-08-2007 09:16:35

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	417,5	24,20	0,98	150,8	8,74
Total powder:	314,7	24,20	0,98	113,7	8,74

Concrete

Concrete Id: P20 Lynis-2

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2111	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,2396 kg Mixing time: 28-03-2007 13:37:00 Mixing temp.: 23,7 °C

Haybox

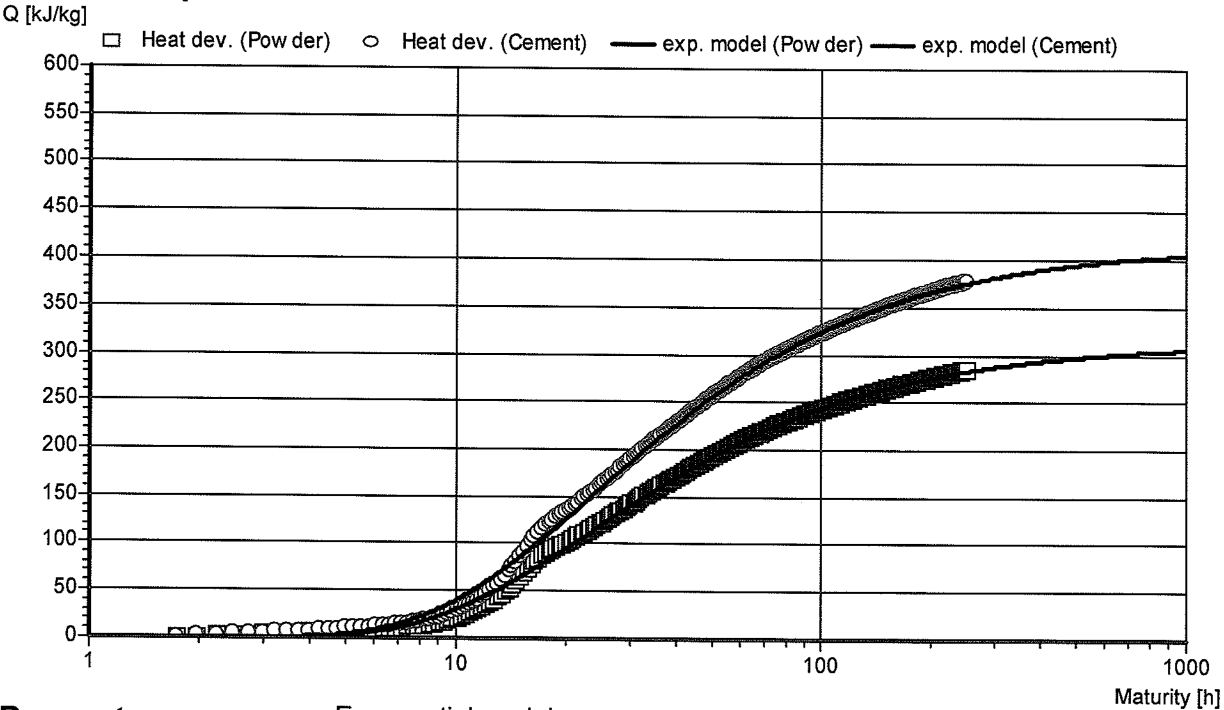
Haybox Id: Høkasse nr. 5

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 LYNIS3.prj Printed: 31-08-2007 09:19:50

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	415,2	23,99	0,97	148,8	8,60
Total powder:	313,0	23,99	0,97	112,2	8,60

Concrete

Concrete Id: P20 Lynis-3

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2094	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,6578 kg Mixing time: 18-04-2007 13:00:00 Mixing temp.: 19,7 °C

Haybox

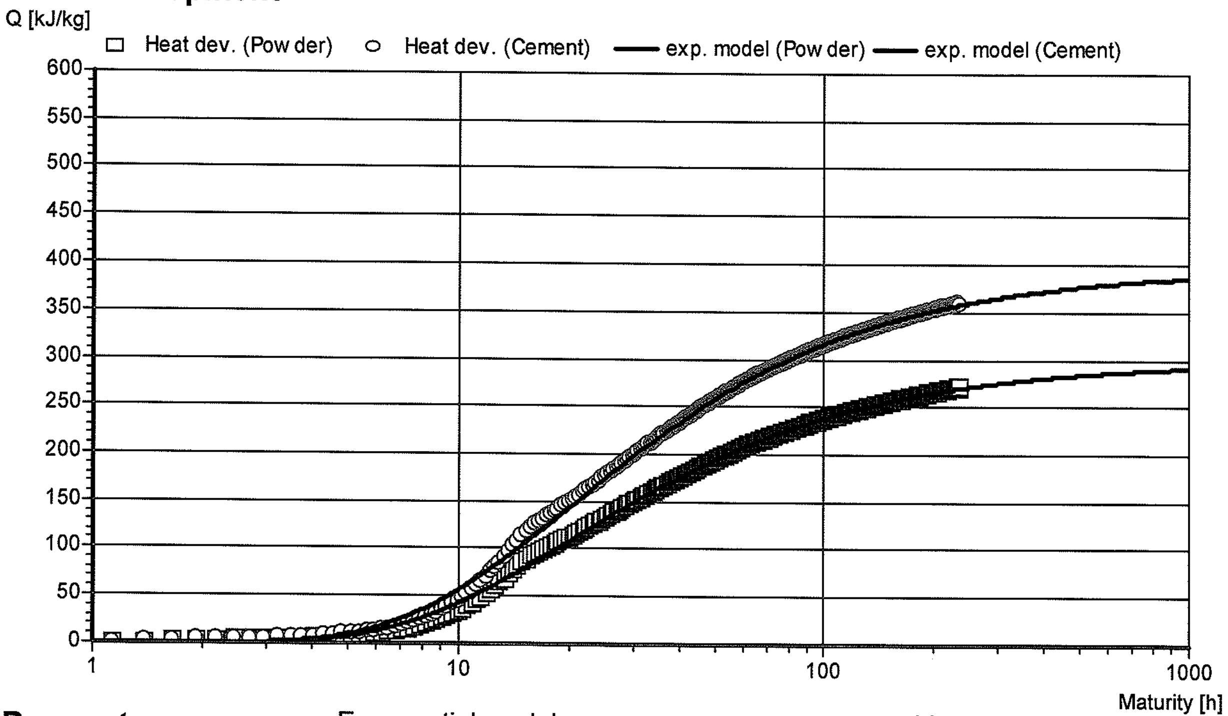
Haybox Id: Høkasse nr. 10

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 AWS1.prj Printed: 31-08-2007 09:27:57

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	395,4	20,38	0,94	136,3	7,01
Total powder:	298,0	20,38	0,94	102,7	7,01

Concrete

Concrete Id: P20 AWS-1

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2018	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,147 kg Mixing time: 25-04-2007 09:25:00 Mixing temp.: 20,8 °C

Haybox

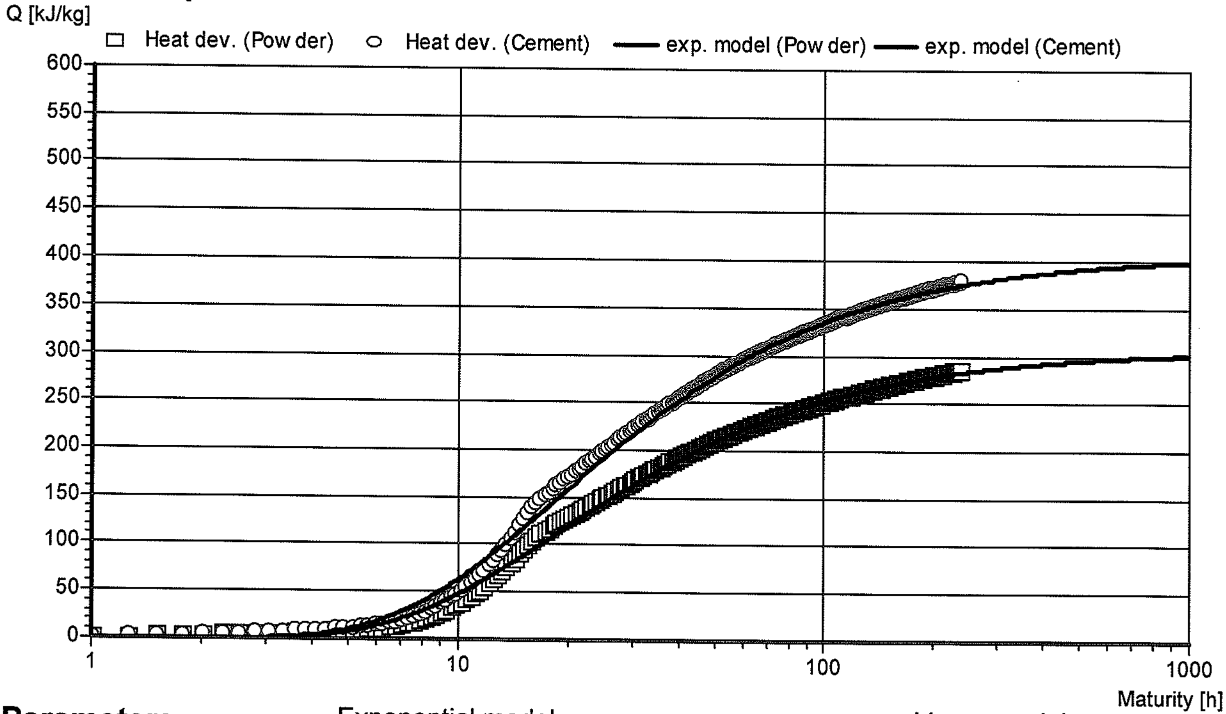
Haybox Id: Høkasse nr. 15

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 AWS2.prj Printed: 31-08-2007 09:25:46

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	407,0	18,93	0,98	147,0	6,83
Total powder:	306,8	18,93	0,98	110,8	6,83

Concrete

Concrete Id: P20 AWS-2

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2095	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,3328 kg Mixing time: 21-03-2007 13:00:00 Mixing temp.: 20,2 °C

Haybox

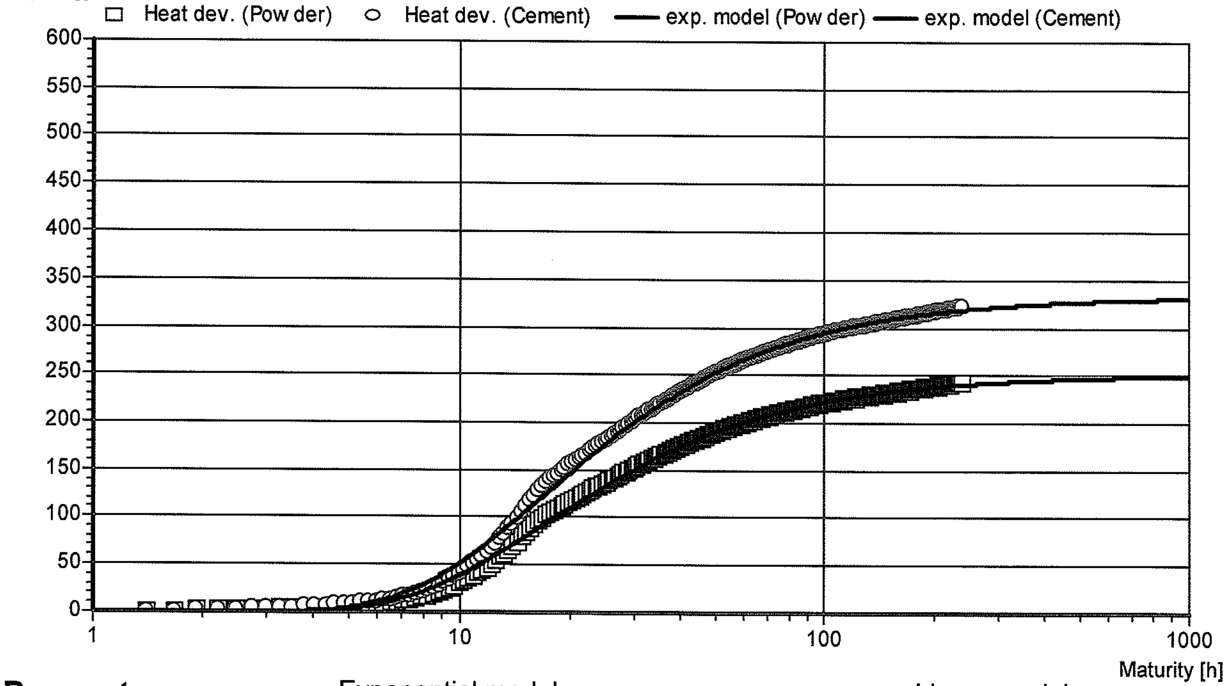
Haybox Id: Høkasse nr. 15

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: P20 AWS3.prj Printed: 03-09-2007 12:14:23

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	332,9	16,99	1,18	144,6	7,28
Total powder:	250,9	16,99	1,18	109,0	7,28

Concrete

Concrete Id: P20 AWS-3

Cement:	211,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	69,1	kg/m³	Density:	2104	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	280,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,3429 kg Mixing time: 26-03-2007 12:10:00 Mixing temp.: 21,1 °C

Haybox

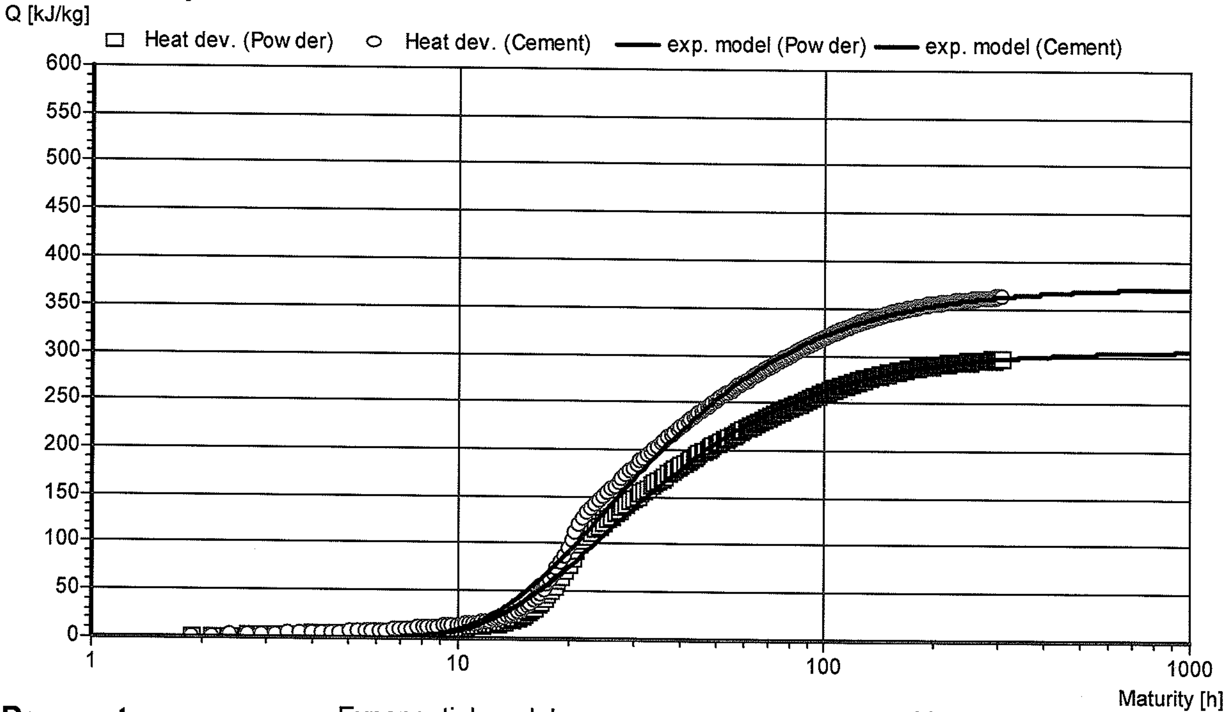
Haybox Id: Høkasse nr. 2

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: A35 B4 LYNIS1.prj Printed: 31-08-2007 12:47:17

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	373,9	25,53	1,38	189,9	12,37
Total powder:	306,4	25,53	1,38	155,6	12,37

Concrete

Concrete Id: A35 Lynis-1

Cement:	348	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	76,6	kg/m³	Density:	2219	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	424,6	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,8509 kg Mixing time: 07-03-2007 12:27:00 Mixing temp.: 20,8 °C

Haybox

Haybox Id: Høkasse nr. 2

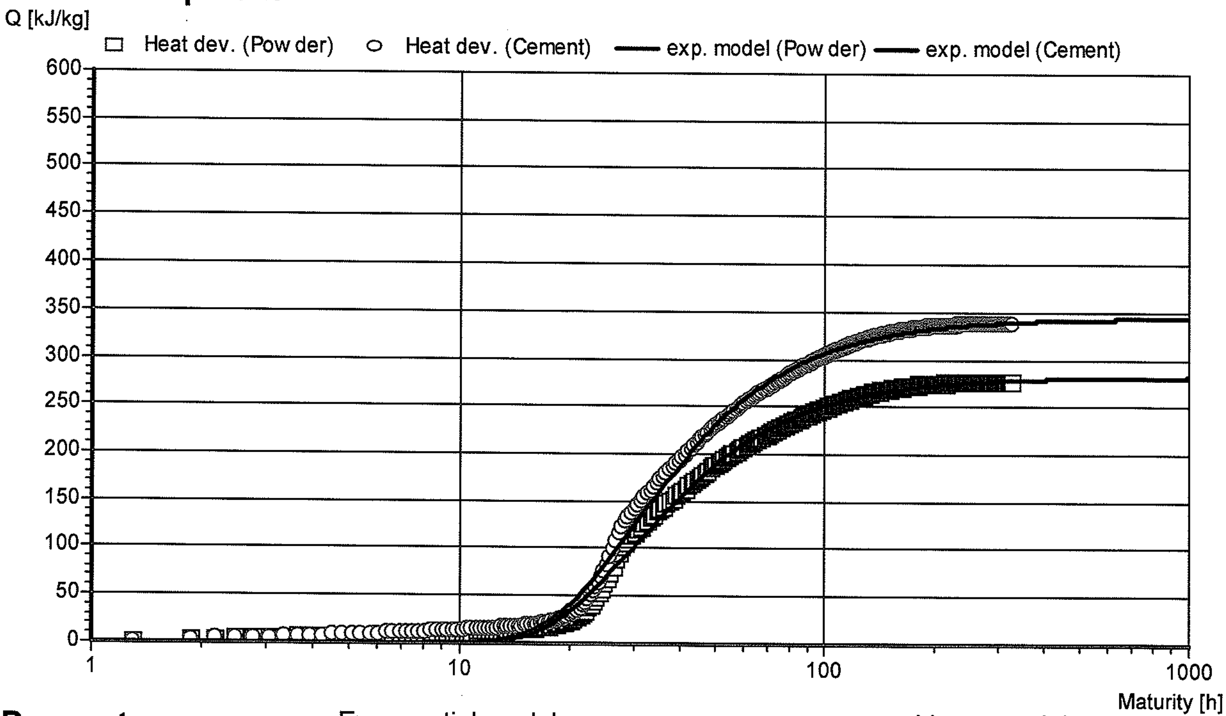
Note

Teknologisk Institut, Beton
Gregersensvej
2630 Taastrup

4C-Heat
Heat development

Init.: Project: A35 LYNIS2.prj Printed: 31-08-2007 12:58:16

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	343,6	30,39	1,81	228,4	17,48
Total powder:	281,6	30,39	1,81	187,2	17,48

Concrete

Concrete Id: A35 Lynis-2

Cement:	348	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	76,6	kg/m³	Density:	2173	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	424,6	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,7325 kg Mixing time: 14-03-2007 08:52:00 Mixing temp.: 23,1 °C

Haybox

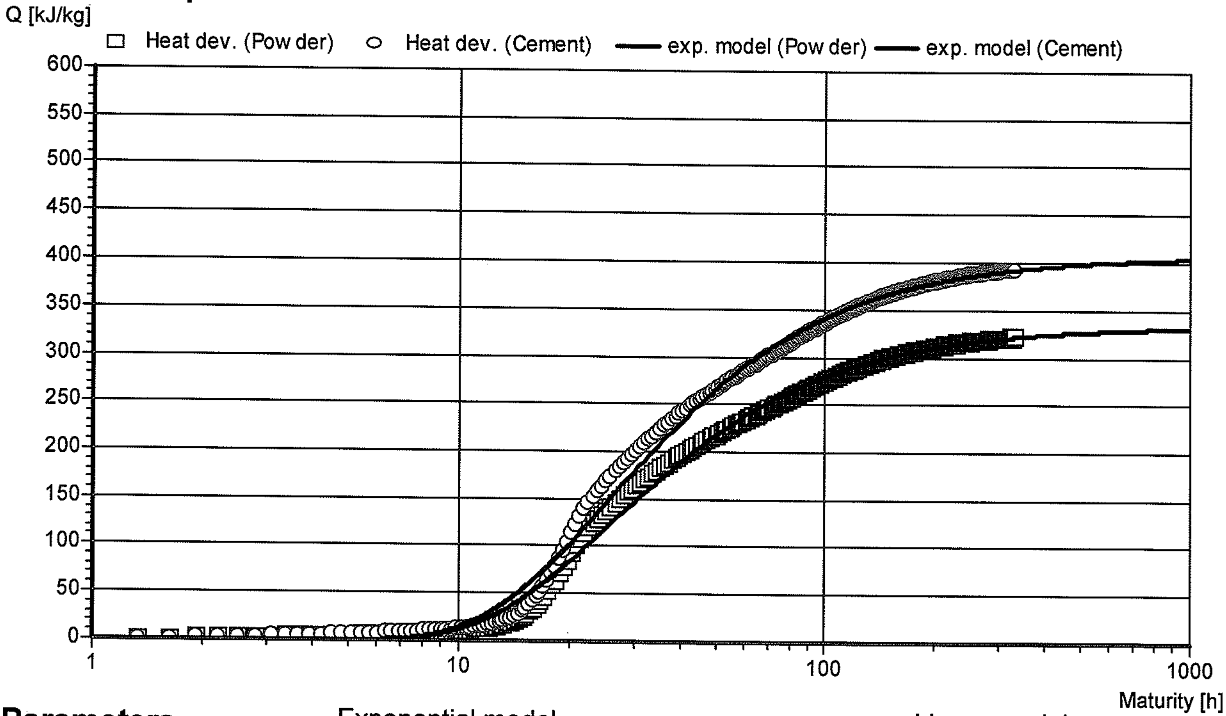
Haybox Id: Høkasse nr. 7

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: A35 B4 lynis3.prj Printed: 31-08-2007 13:00:18

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	407,4	25,81	1,28	191,2	11,78
Total powder:	333,9	25,81	1,28	156,7	11,78

Concrete

Concrete Id: A35 Lynis-3

Cement:	348	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	76,6	kg/m³	Density:	2210	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	424,6	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,7865 kg Mixing time: 16-04-2007 12:50:00 Mixing temp.: 23 °C

Haybox

Haybox Id: Høkasse nr. 7

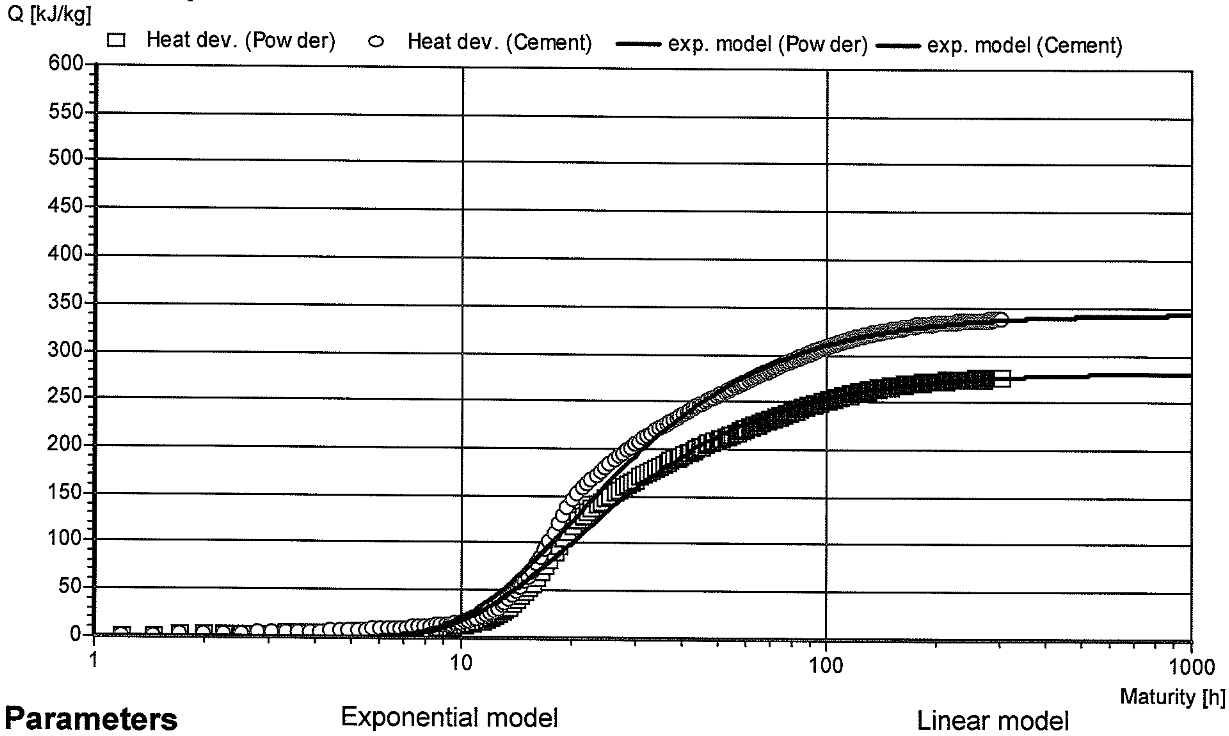
Note

Teknologisk Institut, Beton
Gregersensvej
2630 Taastrup

4C-Heat
Heat development

Init.: Project: ABS AWS1.prj Printed: 31-08-2007 13:13:34

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	343,7	20,51	1,43	181,0	10,20
Total powder:	281,7	20,51	1,43	148,3	10,20

Concrete

Concrete Id: A35 AWS-1

Cement:	336,3	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	74,1	kg/m³	Density:	2133	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	410,4	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 10,945 kg Mixing time: 14-03-2007 12:22:00 Mixing temp.: 21,1 °C

Haybox

Haybox Id: Høkasse nr. 10

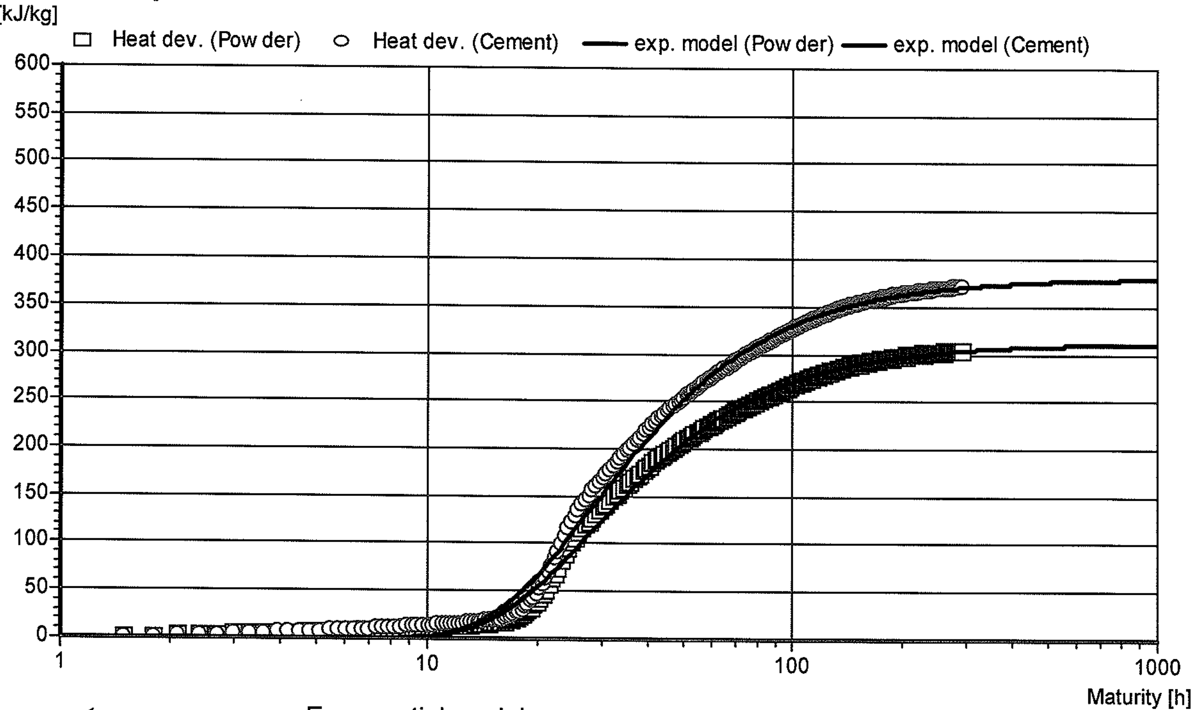
Note

Teknologisk Institut, Beton
Gregersensvej
2630 Taastrup

4C-Heat
Heat development

Init.: Project: A35 AWS2.prj Printed: 31-08-2007 13:09:45

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	380,0	28,58	1,56	218,4	15,07
Total powder:	311,5	28,58	1,56	179,0	15,07

Concrete

Concrete Id: P35 AWS-2

Cement:	336,6	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	74,1	kg/m³	Density:	2231	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	410,7	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,7261 kg Mixing time: 26-03-2007 09:45:00 Mixing temp.: 23,9 °C

Haybox

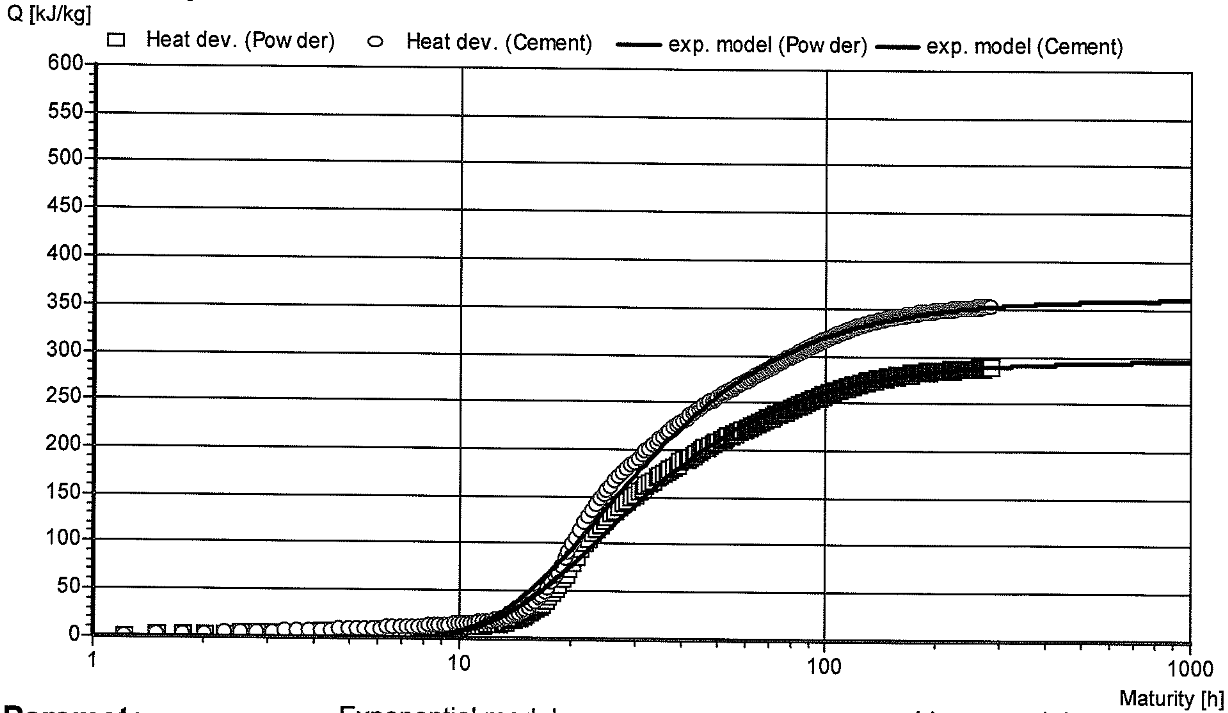
Haybox Id: Høkasse nr. 18

Note

Teknologisk Institut, Beton Gregersensvej 2630 Taastrup	**4C-Heat** **Heat development**

Init.: Project: A35 AWS3.prj Printed: 31-08-2007 13:15:46

Heat development



Parameters

	Exponential model			Linear model	
	Quen [kJ/kg]	Te [hours]	alpha	Qo [kJ/kg]	To [hours]
Cement:	360,8	24,54	1,50	198,5	12,57
Total powder:	295,7	24,54	1,50	162,7	12,57

Concrete

Concrete Id: P35 AWS-3

Cement:	336,3	kg/m³	Spec. heat:	1,05	kJ/kg/°C
Flyash:	74,1	kg/m³	Density:	2133	kg/m³
SilicaFume:	0	kg/m³	Act. factor 1:	33500	J/mol
Total powder:	410,4	kg/m³	Act. factor 2:	1470	J/mol/°C

Sample

Weight: 11,5364 kg Mixing time: 25-04-2007 12:50:00 Mixing temp.: 21 °C

Haybox

Haybox Id: Høkasse nr. 18

Note

Teknologisk Instituts almindelige vilkår for rekvirerede opgaver gælder i deres fulde udstrækning for den ved Teknologisk Institut udførte tekniske prøvning og kalibrering samt for udfærdigelsen af prøvningsrapporter hhv. kalibreringscertifikater i forbindelse hermed.

Dansk Akkreditering (DANAK)

DANAK blev etableret i 1991 med hjemmel i lov nr. 394 om erhvervsfremme af 13. juni 1990.

Kravene til akkrediterede prøvningslaboratorier er fastlagt i Erhvervsfremme Styrelsens bekendtgørelse om akkreditering af laboratorier til teknisk prøvning m.v., samt til GLP-inspektion. Bekendtgørelsen henviser til andre dokumenter, hvor akkrediteringskriterierne er beskrevet yderligere.

Standarderne DS/EN ISO/IEC 17025 "Generelle krav til prøvnings- og kalibreringslaboratoriers kompetence" og DS/EN 45002 "Generelle kriterier for bedømmelse af prøvningslaboratorier" beskriver grundlæggende akkrediteringskriterier. DANAK anvender fortolkningsdokumenter til de enkelte krav i standarderne, hvor det skønnes nødvendigt. Disse vil hovedsageligt være udarbejdet af "European co-operation of Accreditation (EA)" eller "International Laboratory Accreditation Co-operation (ILAC)" med det formål at opnå ensartede kriterier for akkreditering på verdensplan. DANAK udarbejder desuden tekniske forskrifter vedr. specifikke krav til akkreditering, som ikke er indeholdt i standarderne.

For at et laboratorium kan være akkrediteret kræves blandt andet:

- at laboratoriet og dets personale skal være fri for enhver kommerciel, økonomisk eller anden form for pression, som kan påvirke deres tekniske dømmekraft.
- at laboratoriet har et dokumenteret kvalitetsstyringssystem.
- at laboratoriet råder over teknisk udstyr og lokaler af en tilstrækkelig standard til at kunne udføre den prøvning, som laboratoriet er akkrediteret til.
- at laboratorieledelse og -personale har såvel faglig kompetence som praktisk erfaring i udførelsen af den ydelse, som laboratoriet er akkrediteret til.
- at der er indarbejdet faste rutiner for sporbarhed og usikkerhedsbestemmelse.
- at akkrediteret prøvning eller kalibrering udføres efter fuldt validerede og dokumenterede metoder.
- at laboratoriet skal registrere forløbet af akkrediteret prøvning eller kalibrering således, at dette kan rekonstrueres.
- at laboratoriet er underkastet regelmæssigt tilsyn af DANAK.
- at laboratoriet skal have en forsikring, som kan dække laboratoriets ansvar i forbindelse med udførelsen af akkrediterede ydelser.

Rapporter, der bærer DANAK's logo, anvendes ved rapportering af akkrediterede ydelser og viser, at disse er foretaget i henhold til akkrediteringsreglerne.

Appendix F

Strength development

After the casting of the compressive strength samples it was discovered that the pressure meter used for the air content measurement during the casting of the compressive strength samples was malfunctioning, because of this the measured air content in the fresh concrete can not be used in the evaluation of the compressive strength results.

The actual air content of the different concrete mixes has been calculated from the measured cylinder densities. Furthermore the air content for two samples has been analysed according to ASTM C 457 in order to validate the calculated air content.

From the literature it is known that an excessive increase in air content will reduce the compressive strength. A general rule is that an increase of the air content by 1% will reduce the compressive strength by approximately 4%, were the strength reduction is smaller for low air contents and greater for high air contents.

The measured compressive strength and the calculated compressive strength that has been compensated for air content using the rule mentioned above are presented in table 1.

Concrete	Measured Compressive Strength				Calculated Compressive Strength Compensated for Air Content			
	2 days	7 days	28 days	56 days	2 days	7 days	28 days	56 days
A35 AWS-1	16,3	26,6	37,8	45,4	19,6	32,0	45,5	54,6
A35 AWS-2	19,7	37,7	47,6	52,2	21,9	41,8	52,8	57,9
A35 AWS-3	16,6	29,6	35,4	43,4	19,9	35,5	42,4	52,0
A35 Lynis-1	18,7	33,6	44,2	48,1	20,0	35,9	47,2	51,3
A35 Lynis-2	19,7	39	43,1	46,4	21,8	43,2	47,8	51,4
A35 Lynis-3	23,2	34	40,5	48,3	24,9	36,5	43,5	51,9
A35 Ref			33,8				44,8	
P20 AWS-1	4,2	8,1	11,9	14,9	5,9	11,4	16,7	21,0
P20 AWS-2		12,1	18,1	23,1		15,0	22,4	28,6
P20 AWS-3	5,7	11,4	17,6	17,4	7,2	14,4	22,2	22,0
P20 Lynis-1	4,2	9,3	15,9	18,5	5,4	12,0	20,5	23,9
P20 Lynis-2	5,4	11,7	19,1	20,7	6,5	14,1	23,1	25,0
P20 Lynis-3	4,9	11,7	19,1	22,3	6,0	14,4	23,6	27,5

Table 1. Measured and calculated compressive strengths

Plots of the measured strength development are presented in diagrams 1-2 and plots of the calculated strength development are presented in diagrams 3-4.

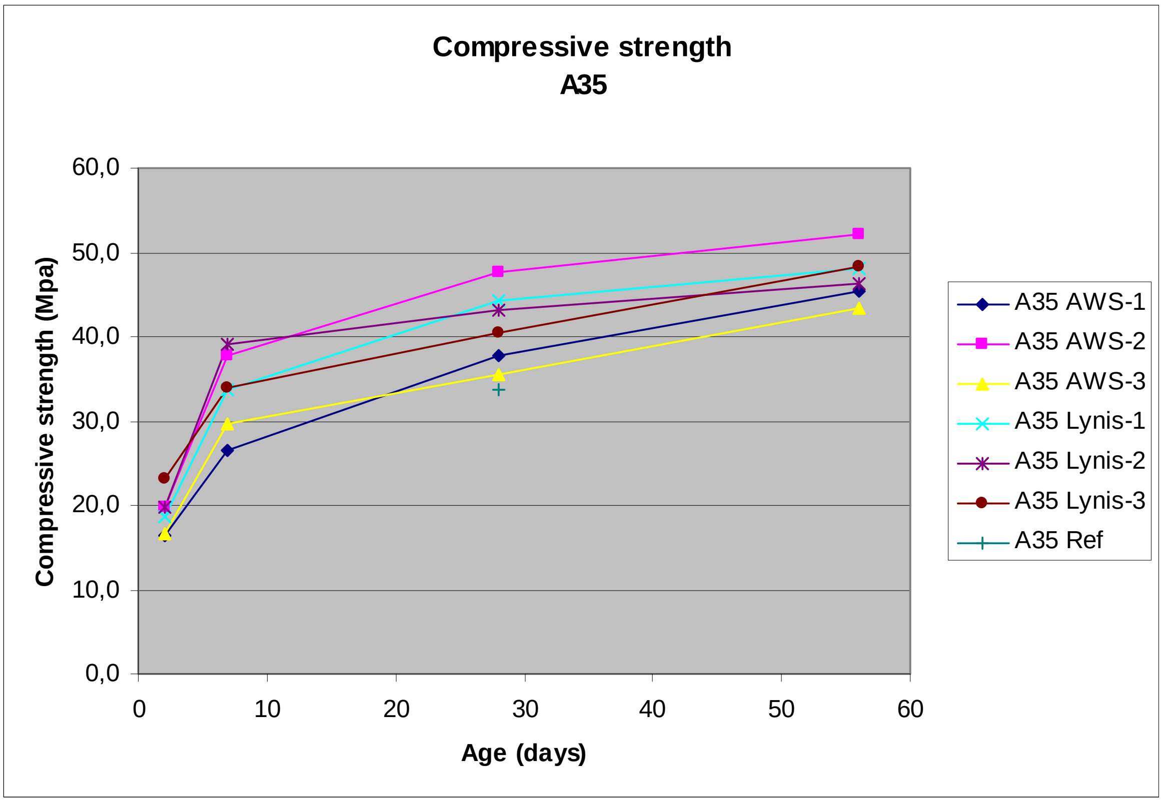


Diagram 1. Measured compressive strength development, A35

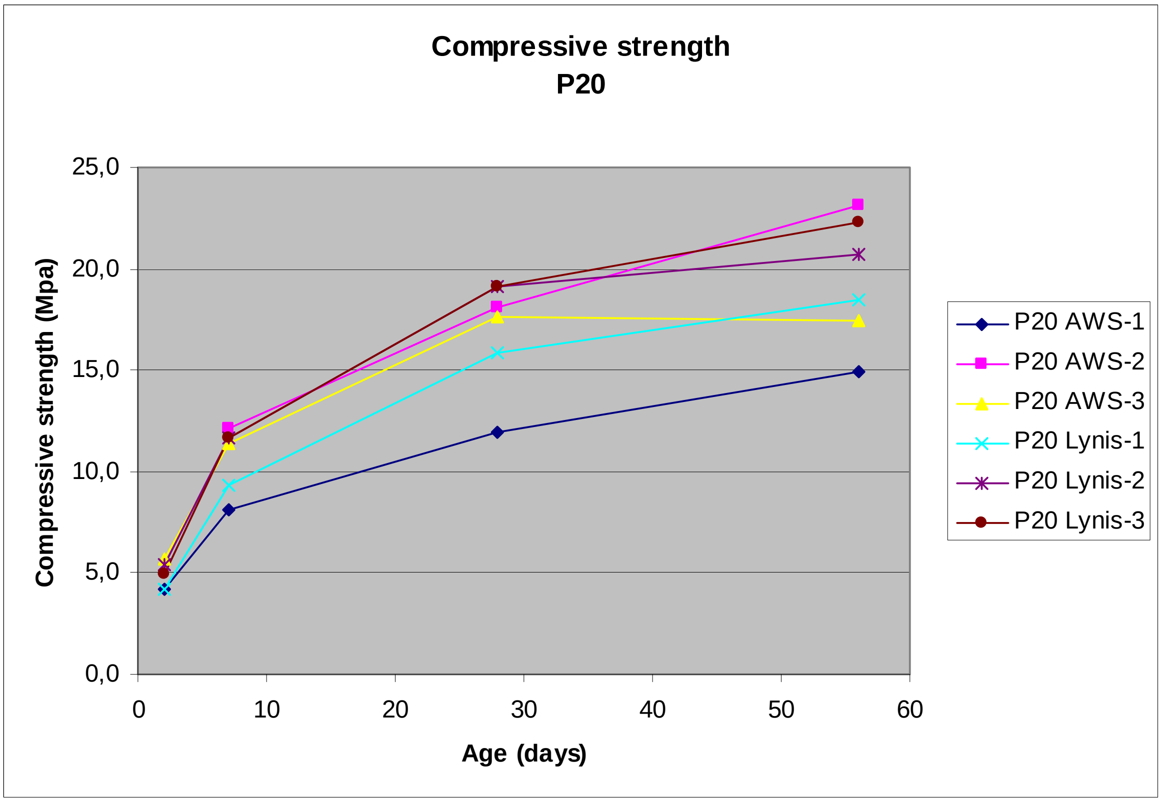


Diagram 2. Measured compressive strength development, P20

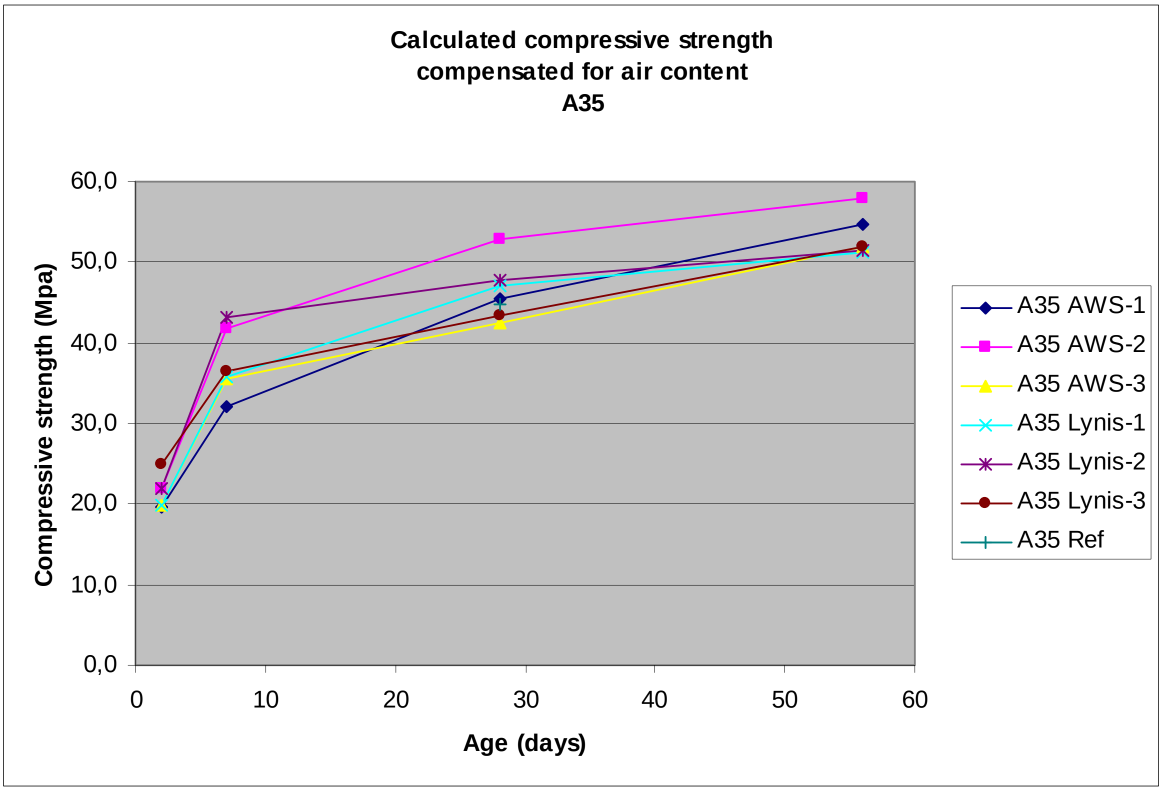


Diagram 3. Calculated compressive strength development, A35

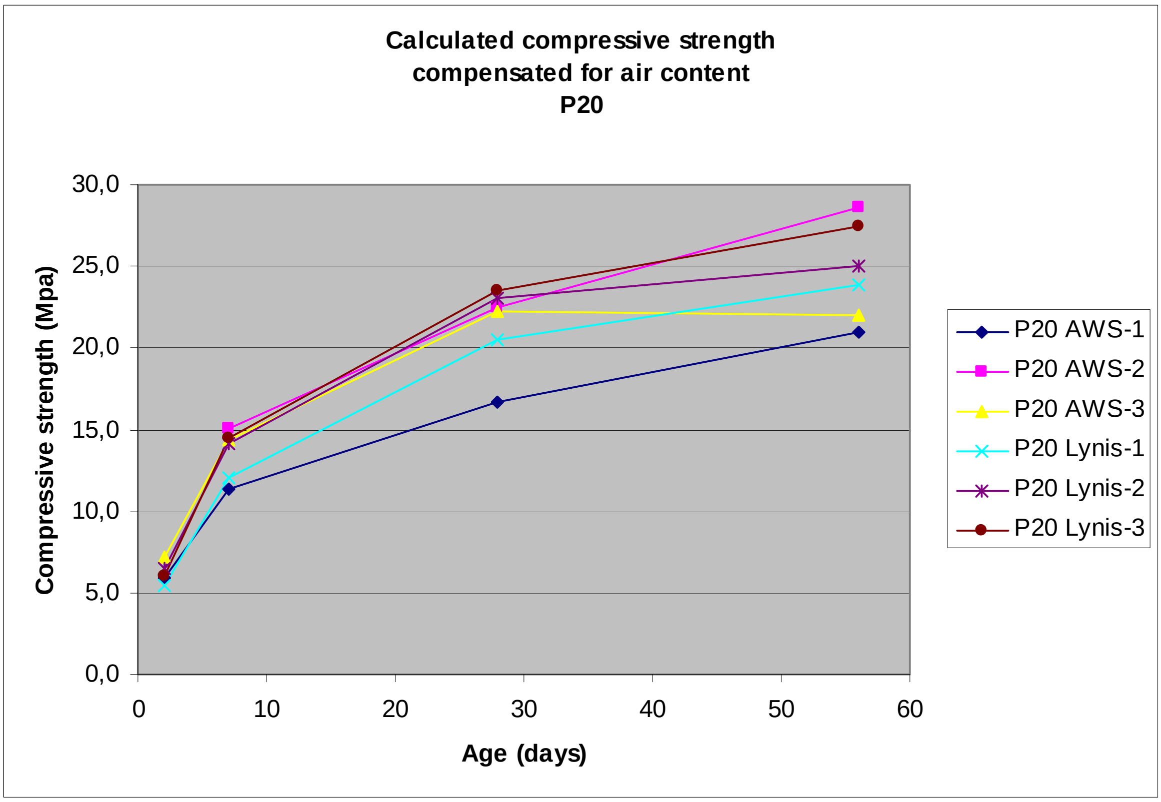


Diagram 4. Calculated compressive strength development, P20