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Aardelite Technology

Aardelite Technology

Turning a residue into a building material

1.1. Introduction and objective

Aardelite pellets were used as natural gravel replacement for the construction of a housing compound consisting of 120 units for retired people at Dronten in the Netherlands. The compound consists of multiple-story buildings and is surrounded by single-level houses.

In consultation with the Ministry of Housing, Land Development and Environmental Affairs and the owner, "Oostelijk Flevoland" Housing Corporation, it was decided that Aardelite gravel would be used in a number of houses to demonstrate the behaviour of Aardelite gravel in concrete construction. In order to compare the workability and final quality of Aardelite concrete to traditional concrete, the walls of four single-level houses were made with Aardelite concrete; an identical block of four houses was made with traditional concrete.

The objective of this demonstration project was to prove that with the use of Aardelite gravel, the same concrete qualities would be met as with traditional natural gravel concrete, without special additives or precautions. Both blocks of houses were executed with the same type and quantity of cement, the same reinforcement, and no addition of plasticizers.

A number of walls were poured in both blocks of houses using a concrete bucket.

In order to demonstrate the workability of Aardelite's round shaped gravel during pumping, one concrete pour was executed with a concrete pump.

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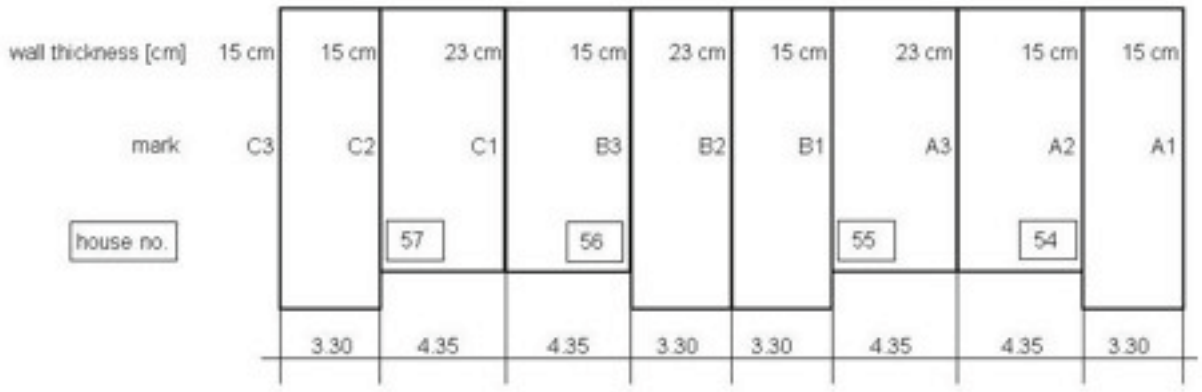
1.2. Definition of the building project

Project: Housing compound Dronten, 120 houses for retired people
Owner: Housing Corporation "Oost Flevoland"
Design: Van Heelsbergen-Jansen Architects, Arnhem
Contractor: H. de Vries B.V., Emmeloord
Ready-Mix plant: Flevoland B.V., Lelystad / Dronten

The sizes, reinforcement and pouring data are shown in the lay-out and table below.



Mark	Wall	House no.	Length [meter]	Thickness, [mm]	Lock-woven Mesh [mm]
A1	Inner leaf of external wall	54	11.40	150	08-20/25
A2	Inside wall	54	10.30	150	08-20/25
A3	Separating wall	54	10.10	230	None
B1	Inside wall	55	10.30	150	08-20/25
B2	Separating wall	55 56	10.60	230	None
B3	Inside wall	56	10.30	150	08-20/25
C1	Separating wall	56 57	10.10	150	None
C2	Inside wall	57	10.30	150	08-20/25
C3	Inner leaf of external wall	57	11.40	150	08-20/25

1.3. Composition and quality of the concrete

The required concrete quality was B17.5 (Dutch standard) with 320 kg cement per m³ concrete.

In those cases where the shuttering (concrete pouring mold) had to be removed the next morning due to the weather conditions, a 50/50 mixture of blast furnace cement (HOA) and portland rapid hardening cement (PCC) was used.

There were no additives added to the concrete mixtures.

The composition and quality of the Aardelite concrete was kept the same as the concrete using the traditional natural gravel.

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Aardelite pellets size 4 - 16 mm were used as natural gravel replacement.

See attachments I to VI for the mixture calculations of the Aardelite based concrete and screen analyses of the aggregate of three individual batches.

1.4. Execution

The Aardelite concrete pours were performed in three days; every day three concrete pours were done, making nine walls in total.

Present at the first concrete pour were:

Supervisor: E.J. Westerink, for the principal
Manager: B. Maandag, for the contractor
Chief foreman: J. Klasen, for the contractor
Foreman: A. Wakker, for the contractor
Building inspectors: Mr. van Tol and Mr. de Boer
Concrete technologist: A.Th. de Haan
Vliegasunie: J. Dubbers and B. Scheurs
Consultant: Prof. ir. J.A.H. Hartmann
Project manager: Ir. A.B. Winkel, for Aardelite BV

All walls appeared to be perfectly smooth after removal of the shuttering elements.

Shuttering elements were used throughout the whole project.

The first concrete pour was done in the early afternoon using a concrete bucket. The next day, after 17 hours curing, the shuttering elements were removed.

The second concrete pour was done on a Friday in the early afternoon, using a concrete bucket. The following Monday morning, after 65 hours curing, the shuttering elements were removed.

The third concrete pour was pumped using a mobile Schwing-Stetter concrete pump. The next day, after 17 hours curing, the shuttering elements were removed.

1.5. Physical properties of the cured concrete

Compressive strength was measured after 7, 14 and 28 days of curing. See attachments VII, VIII, and IX for an overview of the test results.

A visual inspection after two months revealed no differences between the Aardelite concrete surface and the traditional natural gravel concrete.

1.6. Evaluation of Aardelite based concrete

The workability of Aardelite concrete is good and comparable with natural gravel concrete; both concretes have identical water/cement ratios. The workability of the Aardelite concrete when using a mobile concrete pump for pouring was excellent; in fact, due to the round shape of the Aardelite pellets, operation of the pump was even smoother than with traditional concrete. Neither the foreman and workers on site nor the operators of the ready mix concrete plant noticed any difference in workability between Aardelite concrete and traditional concrete when weighing, dosing, or mixing in the ready mix concrete plant, or in pouring using a bucket.

The strength development and final strength of Aardelite concrete is comparable with natural gravel concrete.

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1.7 Supplementary research of the cured concrete

1.7.1 Air sound insulation measurements

In order to compare the Aardelite concrete properties with traditional concrete, air sound insulation measurements were performed by TNO/TPD (Institute of Applied Physics) on Aardelite as well as natural gravel concrete.

The table below shows an overview of the measured air sound insulation indices for air sound between the separating walls of the houses on ground level (horizontal direction).

Measurement	Concrete type	Transmitting-room	Receiving-room	Insulation-index I_{1u} [db]
1	Taditional	Living room	Living room	+4
2	Taditional	Kitchen	Kitchen	+6
3	Taditional	Living room	Living room	+7
4	Taditional	Kitchen	Kitchen	+9
5	Aardelite	Living room	Living room	+5
6	Aardelite	Kitchen	Kitchen	+3
7	Aardelite	Living room	Living room	+6
8	Aardelite	Kitchen	Kitchen	+5

The conclusion of TPD is that both the houses built with Aardelite concrete and those built with traditional concrete in Dronten are within limits of the Dutch standard NEN 1070 (I_{1u} = 0dB). The houses with Aardelite concrete walls showed on average a slightly lower I_{1u} value than the houses with traditional concrete walls (the difference was 1.7 dB). The difference is partly due to the difference in concrete density, with Aardelite concrete at 2100 kg/m³ and traditional concrete at 2400 kg/m³. The remainder of the difference is most likely due to measurement inaccuracies. The course of the insulation curve in the measured situations with or without Aardelite concrete is not significantly different.

1.7.2 Determination of the coefficient of heat conductivity

The coefficient of heat conductivity was also measured by TPD. The average λ values are for:

- Aardelite concrete λ = 0.84 W/mK
- Traditional concrete λ = 1.0 W/mK

(W/mK: Watt per meter Kelvin)

Based on the lower density of the Aardelite pellets, the expected heat conductivity of the Aardelite concrete is 10% to 20% lower.

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1.7.3 Anchorage of fasteners

The building industry uses significant numbers of plugs and anchors. To judge the workability and behaviour of the different types of plugs and anchors in Aardelite concrete, the Fisher company performed a short study.

It was concluded that the behaviour and workability in both concrete types was the same, although drilling and cutting in Aardelite concrete is easier because Aardelite pellets are not as hard as natural gravel.

This picture shows the different types of fasteners used.

2.1 Aardelite pellets

The Aardelite pellets used for this project were made from pulverized coal fly ash made available at a power station in Nijmegen, the Netherlands. The composition of the Aardelite pellets was as follows:

- fly ash 79.7%
- CaO 3.3%
- water 17.0%

The Aardelite pellet properties were as follows:

- Pellet strength 4 MPa
- Bulk density (as produced) 1050 kg/m³
- Specific density 1700 kg/m³
- Moisture content (water as % of total weight) 17%

Aardelite pellets being transported.

After production, the Aardelite pellets were transported by truck to Flevoland Ready mix batching plant for intermediate storage.

3.1 Aardelite process description

The pellets used in the concrete are made using the Aardelite process. The Aardelite technology is based on the activation and control of pozzolanic reactions in the fly ash/lime/water mixture by using the pozzolanic properties of fly ash. During these reactions (dissolution of silicon and aluminum in the presence of lime and water), a tobormorite-like gel is formed which, on a micro scale, is able to 'cement' the 'inert' particles. The resulting product is a stone-like matrix.

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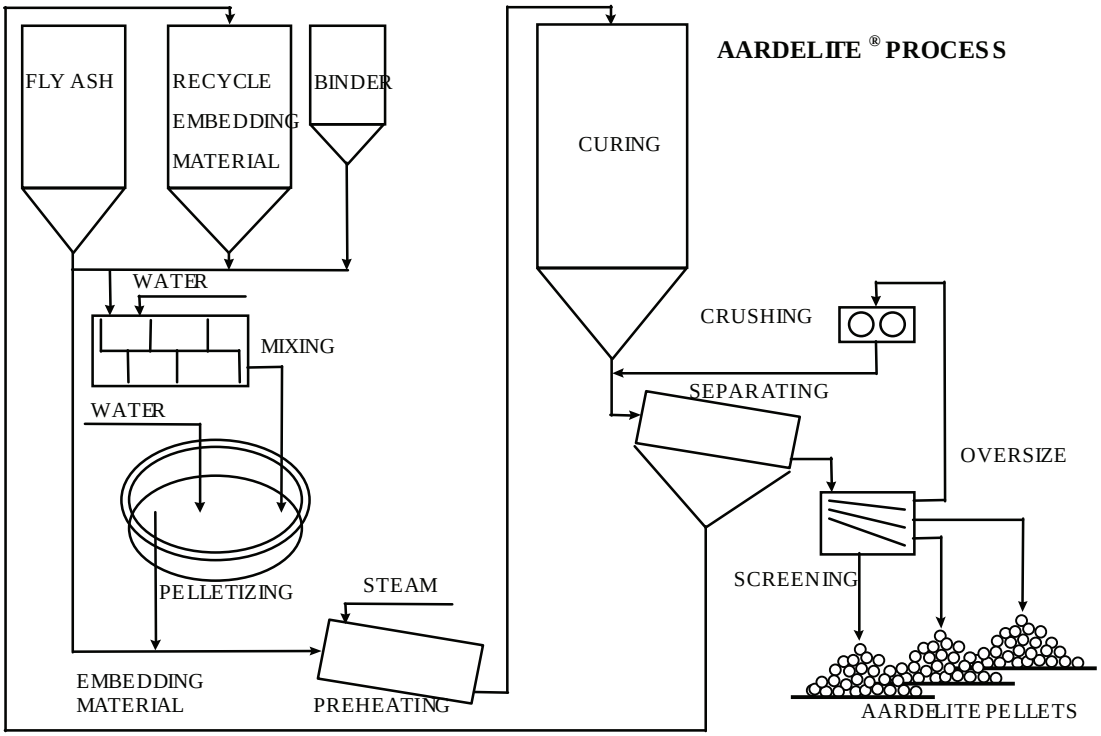
The reaction mechanisms can be summarized as follows:

$CaO + H_2O$ > $Ca(OH)_2$
$SiO_2 + Ca(OH)_2 + H_2O$ > $Si(OH)_4 + CaO$
$Si(OH)_4 + CaO + H_2O$ > $CaO{\bullet}SiO_2{\bullet}3H_2O$ (calcium silicate hydrate)

$CaO + H_2O$ > $Ca(OH)_2$
$2AI_2O_3 + 3Ca(OH)_2 + 3H_2O$ > $4AI(OH)_3 + 3CaO$
$4AI(OH)_3 + 3CaO + H_2O$ > $3CaO \bullet 2AI_2O_3{\bullet}7H_2O$ (calcium aluminate hydrate)

These reactions are accelerated at a temperature of 90° Celsius and 100% relative humidity.

The Aardelite production process is presented below.



The Aardelite process is a continuous process where fly ash, recycled embedding material (fly ash which has been used as embedding material), and lime are fed into the mixer in accordance with the pre-determined recipe. In the first mixing phase, fly ash and lime are mixed thoroughly. After the addition of water, the second mixing phase takes place, which results in the even distribution of the micro-sized particles of fly ash and lime.

The material from the mixer, the so called green mix, is fed onto the pelletizer through a delumper in order to prevent conglomerated green mixture from entering the pelletizer. On the pelletizing disk, pellets of the desired size range are formed. The mechanism of the pelletizing process is based on the conglomeration of fine particles through rotating the particles under an angle, while spraying water. The size of the pellets is determined by the amount of water added at the pelletizing disk and the rotating speed of the pelletizer.

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Pellets leaving the pelletizer, the so-called green pellets, are embedded in dry fly ash to prevent them from sticking together during the curing process. In the rotary preheater, where the embedding process takes place, steam is injected to preheat the embedded green pellets to 90° Celsius. The heated embedded green pellets are fed into the curing silo, where the desired pozzolanic reactions take place. The time required for these reactions is about 20 hours. The silo is designed in such a way that a continuous mass flow is assured, as well as the required retention time.

The embedded cured pellets from the curing silo are fed into a rotary screen to separate the pellets from the embedding fly ash, after which this fly ash is re-used in the mixer again. The cured pellets are separated in the desired size ranges. Over-size pellets are crushed and returned to the rotary screen. The process is free of any waste streams.

The Aardelite pelletizer.

ATTACHMENT I: First Concrete Pour

Flevoland B.V. Dronten.

Contractor: Bouwbedrijf H. de Vries B.V. Emmeloord
Project: Housing compound for retired people, Dronten.

Calculation of Aardelite concrete mixture:

165	kg	Blast furnace cement	=	56	ltr
165	kg	Portland cement	=	52	ltr
Air	1%		=	10	ltr
Water		(w/c ratio 0.50)	=	163	ltr
Total volume				281	ltr
		Remaining for aggregate		719	ltr

Calculation of the aggregates:

38% sand 273.2 ltr x 2.64 kg/ltr 721 kg dry sand 30 kg moist (4.2 %)	62% Aardelite 445.8 ltr x 1.70 kg/ltr 758 kg dry Aardelite 129 kg moist (17%)	Water 163 ltr required - 30 (water content sand) - 129 (water content Aardelite) + 136 (absorption 18% in Aardelite)
751 kg sand incl. moist	887 kg Aardelite incl. moist	140 ltr water

Weigh out (rounded off) per m^3 concrete:

- 165 kg BF cement
- 165 kg PC cement
- 750 kg sand
- 890 kg Aardelite
- 140 ltr water

Note: 1 kg = 2.204 lb
1 ltr = 0.26 US gallon
1 m^3 = 1,000 ltr
1 mm = 1,000 µm (micron)
1 mm = 0.0394 inch

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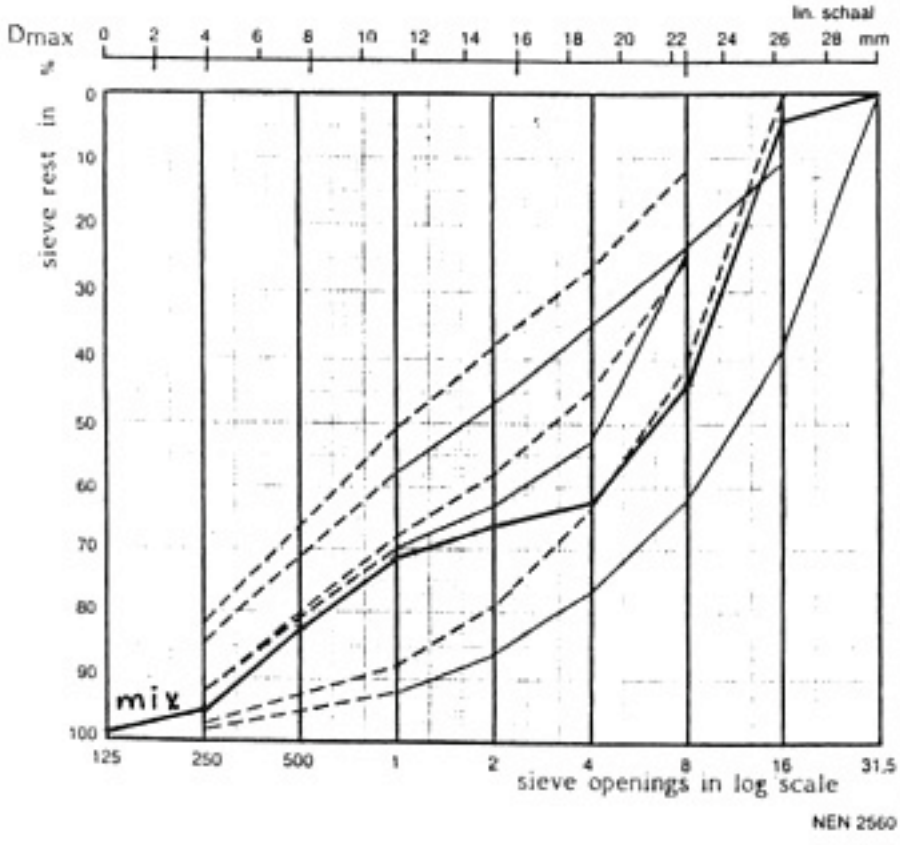
ATTACHMENT II, First Concrete Pour Screen Analyses

origin: coarse sand : Lower Rhine FRG
Aardelite 4-16 : Nunspeet NETH

nr:
laboratory:

project : Bejaardencentrum Dronten
contractor : Bouwbedrijf H.de Vries B.V.
subject : WALLS

sieves acc. NEN 2560	sand	Aardelite	38 % sand	62 % A.E.	mix		mix
C 31,5		0.0		0.0	0.0		0.0
C 16		6.1		3.78	3.78		3.8
C 8		71.1		44.45	44.45		44.45
C 4	7.8	96.7	2.96	59.96	62.92		62.9
2 mm	16.3	97.1	6.19	60.20	66.39		66.4
1 mm	28.2	97.2	10.72	60.26	70.98		71.0
500 µm	56.5	97.5	21.46	60.45	81.92		81.9
250 µm	93.6	98.0	35.57	60.76	96.33		96.3
125 µm	99.4	98.8	37.77	61.26	99.03		99.0
F	301.8	663.1	114.68	411.12	525.80		525.8
%	3.02	6.63	114.7	441.1	525.8		5.26



organic impurities none

fines <63 µm none

D_{max} gravel abt.16mm

sand	38	%
	—	%
gravel	—	%
Aardelite	62	%
total fines < 250 µm:	135	l
air	1.0	%

supply:
a. by composition
b. by compressive strength
class B 17.5

composition

PC/BCF	165/165	kg
brand	ENCI/CEMY	
sand	721	kg
Aardelite	758	kg
gravel	—	kg
tot.water	299	ltr
additive	none	
brand	—	
qty	—	
absorption	136	ltr
w/c ratio	0.50	

slump 120 mm

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ATTACHMENT III, Second Concrete Pour

Flevoland B.V. Dronten.

Contractor: Bouwbedrijf H. de Vries B.V. Emmeloord
Project: Housing compound for retired people, Dronten.

Calculation of Aardelite concrete mixture:

320	kg	Blast furnace cement	=	109	ltr
Air	1%		=	10	ltr
Water		(w/c ratio 0.52)	=	166	ltr
Total volume				285	ltr
		remaining for aggregate		715	ltr

Calculation of the aggregates:

38% sand 271.7 ltr x 2.64 kg/ltr 717 kg dry sand 26 kg moist (3.6%)	62% Aardelite 443.3 ltr x 1.70 kg/ltr 754 kg dry Aardelite 128 kg moist (17%)	Water 166 ltr required - 26 (water content sand) - 128 (water content Aardelite) + 136 (absorption 18% in Aardelite)
743 kg sand incl. moist	882 kg Aardelite incl. moist	148 ltr water

Weigh out (rounded off) per m^3 concrete:

- 320 kg BF cement
- 745 kg sand
- 880 kg Aardelite
- 148 ltr water

Note: 1 kg = 2.204 lb
1 ltr = 0.26 US gallon
1 m^3 = 1,000 ltr
1 mm = 1,000 µm (micron)
1 mm = 0.0394 inch

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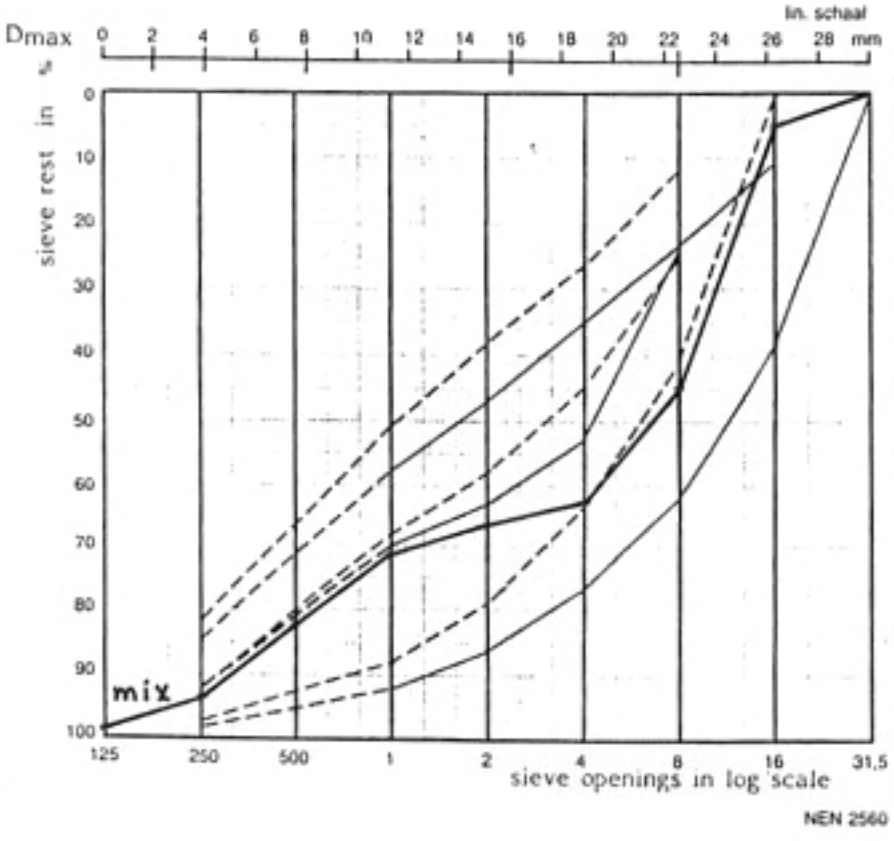
ATTACHMENT IV, Second Concrete Pour Screen Analyses

origin: coarse sand : Lower Rhine FRG
Aardelite 4-16 : Nunspeet NETH

nr:
laboratory:

project : Bejaardencentrum Dronten
contractor : Bouwbedrijf H.de Vries B.V.
subject : WALLS

sieves acc. NEN 2560	sand	Aardelite	38 % sand	62 % A.E.	mix		mix
C 31,5		0.0		0.0	0.0		0.0
C 16		6.1		3.78	3.78		3.8
C 8		71.1		44.45	44.45		44.5
C 4	7.8	96.7	2.96	59.96	62.92		62.9
2 mm	16.3	97.1	6.19	60.20	66.39		66.4
1 mm	28.2	97.2	10.72	60.26	70.98		71.0
500 µm	56.5	97.5	21.47	60.45	81.92		81.9
250 µm	93.6	98.0	35.57	60.76	96.33		96.3
125 µm	99.4	98.8	37.77	61.26	99.03		99.0
F	301.8	663.1	114,68	411.12	525.80		525.8
%	3.02	6.63	114.7	411.1	525.8		5.26



organic impurities none

fines <63 µm none

D_{max} gravel abt.16mm

sand	38 %
	— %
gravel	— %
Aardelite	62 %
total fines < 250 µm:	135 l
air	1.0%

supply:
a. by composition
b. by compressive strength
class B 17.5

composition

PC / BCF	320	kg
brand	CEMY-A	
sand	717	kg
Aardelite	754	kg
gravel	—	kg
tot.water	302	ltr
additive	none	
brand	—	
qty	—	
absorption	136	ltr
w/c ratio	0.52	

slump 120 mm

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ATTACHMENT V, Third Concrete Pour

Flevoland B.V. Dronten.

Contractor: Bouwbedijf H.de Vries B.V. Emmeloord
Project: Housing compound for retired people, Dronten

Calculation of Aardelite concrete mixture:

160	kg	Blast furnace cement	=	54	ltr
160	kg	Portland cement	=	51	ltr
Air	1%		=	10	ltr
Water		(w/c ratio 0.50)	=	160	ltr
Total volume				275	ltr
		Remaining for aggregate		725	ltr

Calculation of the aggregates:

38% sand 275.5 ltr x 2.64 kg/ltr 727 kg dry sand 28 kg moist (3.9%)	62% Aardelite 449.5 ltr x 1.70 kg/ltr 764 kg dry Aardelite 128 kg moist (16.8%)	Water 160 ltr required - 28 (water content sand) - 128 (water content Aardelite) + 136 (absorption 18% in Aardelite)
755 kg sand incl. moist	892 kg Aardelite incl. moist	140 ltr water

Weigh out (rounded off) per m^3 concrete:
- 160 kg BF cement
- 160 kg PC cement
- 755 kg sand
- 890 kg Aardelite
- 140 ltr water

Note: *1 kg = 2.204 lb*
1 ltr = 0.26 US gallon
1 m^3 = 1,000 ltr
1 mm = 1,000 µm (micron)
1 mm = 0.0394 inch

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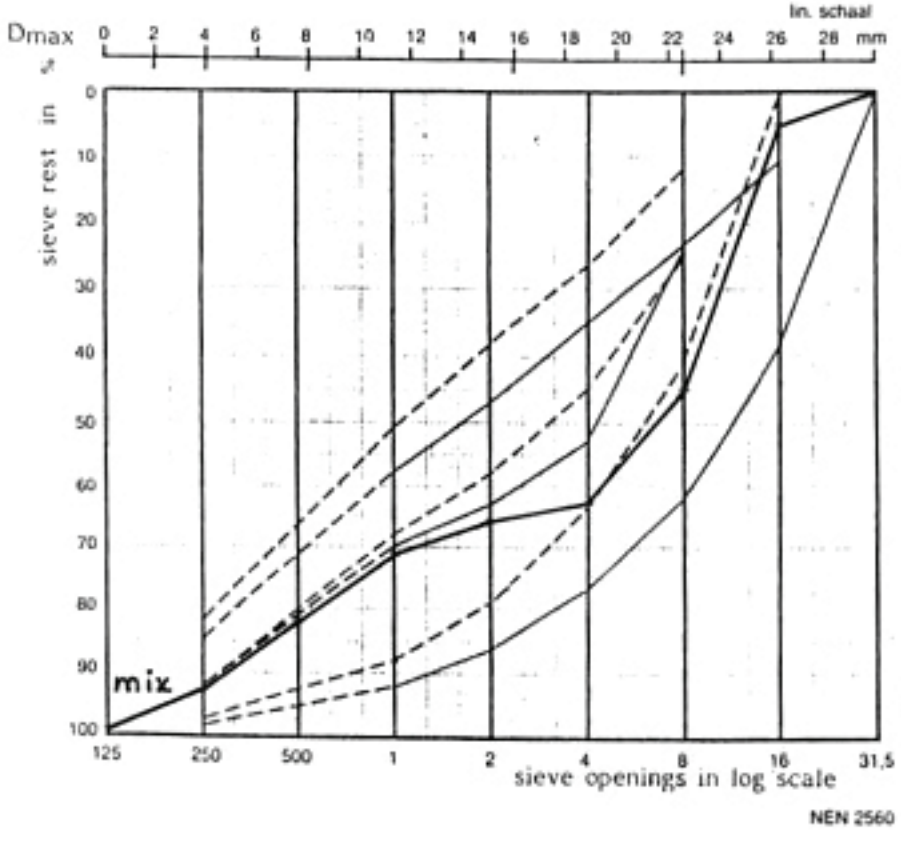
ATTACHMENT VI, Third Concrete Pour Screen Analyses

origin: coarse sand : Lower Rhine FRG
Aardelite 4-16 : Nunspeet NETH

nr:
laboratory:

project : Bejaardencentrum Dronten
contractor : Bouwbedrijf H.de Vries B.V.
subject : WALLS

sieves acc. NEN 2560	sand	Aardelite	38 % sand	62 % A.E.	mix		mix
C 31,5		9.0		0.0	0.0		0.0
C 16		6.1		3.78	3.78		3.8
C 8		71.1		44.45	44.45		44.5
C 4	7.8	96.7	2.96	59.96	62.92		62.9
2 mm	16.3	91.1	6.19	60.20	66.39		66.4
1 mm	28.3	97.2	10.72	60.45	70.98		71.0
500 µm	56.5	97.5	21.47	60.45	81.92		81.9
250 µm	93.6	98.0	35.57	60.76	96.33		96.3
125 µm	99.4	98.9	37.77	61.26	99.03		99.0
F	301.8	663.1	114.68	411,12	525.80		525.8
%	3.02	6.63	114.7	411.1	525.8		5.26



organic impurities none

fines <63 µm none

D_{max} gravel abt.16mm

sand	38	%
	___	%
gravel	___	%
Aardelite	62	%
total fines < 250 µm:	132	l
air	1.0	%

supply:
a. by composition
b. by compressive strength
class B 17.5

composition

PC / BCF	160/160	kg
brand	ENCI/CEMY	
sand	727	kg
Aardelite	764	kg
gravel	___	kg
tot.water	___	ltr
additive	none	
brand	___	
qty	___	
absorption	136	ltr
w/c ratio	0.50	

slump 120 mm

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ATTACHMENT VII

Flevoland B.V. Dronten

Aardelite concrete mixture compressive strength of the first pour.

Load number	1		2		3	
Quantity	6 m^3		6 m^3		6 m^3	
Water dosing	140 ltr		135 ltr		135 ltr	
Concrete mix:						
Slump	140 mm		130 mm		100 mm	
Shake	390 mm		390 mm		330 mm	
Temperature	12° C		12° C		12° C	
Air	0.7 %		1.0 %		---	
Spec. density	2.12 kg/ltr		2.11 kg/ltr		---	
Test cubes:	Spec. density [kg/ltr]	Compr. strength [Mpa]	Spec. density [kg/ltr]	Compr. strength [Mpa]	Spec. density [kg/ltr]	Compr. strength [Mpa]
Strength after:						
7 days	--	--	2.15	33.7	--	--
14 days	--	--	2.14	40.8	--	--
28 days	2.17	40.8	2.16	46.3	2.15	44.7

The average compressive strength after 28 days was 43.9 MPa.

ATTACHMENT VIII

Flevoland B.V. Dronten

Aardelite concrete mixture compressive strength of the second pour.

Load number	1		2	
Quantity	6.5 m^3		6.5 m^3	
Water dosing	148 ltr		148 ltr	
Concrete mix:				
Slump	140 mm		130 mm	
Shake	430 mm		420 mm	
Temperature	12° C		12° C	
Air	0.9 %		---	
Spec. density	2.11 kg/ltr		---	
Test cubes:	Spec. density [kg/ltr]	Compr. strength [Mpa]	Spec. density [kg/ltr]	Compr. strength [Mpa]
Strength after:				
7 days	2.15	23.5	--	--
14 days	2.13	31.4	--	--
28 days	2.14	34.1	2.13	33.7

The average compressive strength after 28 days was 33.9 MPa.

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ATTACHMENT IX

Flevoland B.V. Dronten

Aardelite concrete mixture compressive strength of the third pour.

Load number	1		2	
Quantity	9 m^3		6 m^3	
Water dosing	140 ltr		140 ltr	
Concrete mix:				
Slump	130 mm		140 mm	
Shake	440 mm		450 mm	
Temperature	12° C		12° C	
Air	1.0%		---	
Spec. density	2.13 kg/ltr		---	
Test cubes:	Spec. density [kg/ltr]	Compr. strength [MPa]	Spec. density [kg/ltr]	Compr. strength [MPa]
Strength after:				
7 days	2.18	28.6	--	--
14 days	2.17	36.5	--	--
28 days	2.18	39.6	2.20	36.1

The average compressive strength after 28 days was 37.8 MPa.

Submitted By:
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