THE EFFECT OF A FOAM UPON THE DRYING BEHAVIOUR AND THE LENGTH CHANGES OF A LIGHTWEIGHT CONCRETE WITH VOIDS AND CELLULAR LIGHTWEIGHT AGGREGATES

EINFLUSS EINES SCHAUMS AUF DAS AUSTROCKNUNGS- UND FORMÄNDERUNGSVERHALTEN BEI EINEM HAUFWERKSPORIGEN LEICHTBETON MIT PORÖSEN LEICHTZUSCHLÄGEN

LES EFFETS D'UNE MOUSSE SUR LE COMPORTEMENT AU SECHAGE ET LE RETRAIT D'UN BETON LEGER AVEC CAVITES ET AGREGATS LEGERS

Thomas Popp

SUMMARY

The drying behaviour and the length changes (drying shrinkage) of two different types of lightweight concrete were investigated on wall specimens (125 cm by 125 cm by 30 cm) for a period of 450 days. During this period the specimens were stored in an atmosphere of 20 °C and 65 % relative humidity. In the present study two lightweight concretes should be compared:

- one made of cellular lightweight aggregates of two size fractions (from 4 mm up to 8 mm, from 0 mm up to 4 mm) and of a Portland cement and
- the other made of cellular lightweight aggregates of only one size fraction (from 4 mm up to 8 mm), a Portland cement and a special foam used as an admixture, which was added to the concrete mix in the foamed up state.

The fresh lightweight concrete with foam (LZ) showed a better workability and was easier to compact than the fresh lightweight concrete without foam (L). Moreover the structure of the lightweight concrete LZ proved to be more homogenous than the structure of the lightweight concrete L. With regard to the hardened concrete properties, the lightweight concrete LZ had a dry density lower by 11 %, but a 28-day-compressive strength higher by 13 % in comparison with the corresponding lightweight concrete without foam.

The wall specimens prepared from the lightweight concrete with foam showed a significantly slower drying. The length changes, which were measured on the surface of the wall specimens and mainly caused by the procedure of drying shrinkage, were distinctly different too. The final shrinkage, deter-

mined on standard test specimens (cylinders) from the lightweight concrete LZ, was higher by 0,16 mm/m than that of the corresponding test specimens from lightweight concrete L. This higher shrinkage rate may be due to the higher water content of lightweight concrete LZ.

The length changes of the wall specimen from lightweight concrete L were finished at the concrete age of 450 days. After this period of time the wall specimen from lightweight concrete LZ have only reached 50% of the final shrinkage , which was determined on corresponding standard test specimens (cylinders).

In spite of the wide difference of dry density, both types of lightweight concrete had the same value of thermal conductivity. In consideration of the different dry density the thermal conductivity of lightweight concrete LZ was consequently better than that of lightweight concrete L.

The results of this study showed that using this foam as an admixture in the preparation of lightweight concrete improves the workability and generates a more homogenous structure of lightweight concrete. Though the use of this foam reduced the density, the strength of the lightweight concrete LZ was significantly higher. However other properties, like the drying behaviour, the drying shrinkage and the thermal conductivity were unfavourably influenced.

ZUSAMMENFASSUNG

Über einen Zeitraum von 450 Tagen wurde an Wandelementen (125 cm x 125 cm x 30 cm) von zwei unterschiedlichen haufwerksporigen Leichtbetonen das Austrocknungs- und das Formänderungsverhalten bei Lagerung in dem Normklima 20 °C und 65 % rel. F. beobachtet. Dabei wurde ein Leichtbeton (L), hergestellt aus porigen Leichtzuschlägen der Körnungen 4/8 mm und der Körnung 0/4 mm und einem Portlandzement CEM I 42,5 R, mit einem Leichtbeton (LZ), hergestellt aus porigen Leichtzuschlägen der Körnung 4/8 mm, einem Portlandzement CEM I 42,5 R und einem Schaum als Zusatzmittel, verglichen. Gegenüber dem Frischbeton L ließ sich der Frischbeton LZ mit Schaum leichter verarbeiten und verdichten. Außerdem war das Gefüge des Leichtbetons LZ im Gegensatz zu dem des Leichtbetons L im ausgehärteten Zustand homogener.

Hinsichtlich der Festbetoneigenschaften besaß der Leichtbeton LZ im Vergleich mit dem Leichtbeton L eine um 11% geringere Trockenrohdichte, aber eine um 13 % höhere 28 Tage-Festigkeit.

Dagegen zeigten das Wandelement aus dem mit Schaum hergestellten Leichtbeton LZ ein deutlich langsameres Austrocknen und die entsprechenden

Norm-Prüfkörper ein deutlich größeres Schwindmaß. Das Endschwindmaß der Norm-Prüfkörper lag bei dem Leichtbeton LZ um 0,16 mm/m höher als das des Leichtbetons L. Vermutlich ist dies, auf den höheren Wasseranteil des Frischbetons mit Schaum zurückzuführen.

Die Formänderungen waren bei dem Wandelement aus Leichtbeton L bis zum Zeitpunkt nach 450 Tagen weitgehend abgeschlossen. Dagegen waren nach diesem Zeitraum bei dem Wandelement aus Leichtbeton LZ erst 50 % des Endschwindmaßes der Norm-Prüfkörper erreicht.

Trotz des großen Unterschieds in der Trockenrohdichte wurde an beiden Leichtbetonen der gleiche Wert der Wärmeleitfähigkeit ermittelt. Bezogen auf die trockenrohdichte besaß demzufolge der Leichtbeton LZ mit Schaum eine im Vergleich mit dem Leichtbeton L deutlich höhere Wärmeleitfähigkeit.

Die Untersuchungsergebnissen machten deutlich, daß ein Schaum als Zusatzmittel bei haufwerksporigem Leichbeton die Verarbeitbarkeit verbessern und zu einem gleichmäßigeren Gefüge im Leichtbeton führen kann. Außerdem kann durch den Einsatz eines Schaums bei vergleichsweise niedrigerer Trokkenrohdichte eine höhere Festigkeit bewirken. Andere betontechnologische Eigenschaften, wie Schwindmaß, Wärmeleitfähigkeit und Austrocknungsverhalten werden jedoch eher ungünstig beeinflußt.

RESUME

Le comportement au séchage et la déformation (retrait de séchage) de deux types de béton a été examiné sur des éprouvettes de mur (125 cm x 125 cm x 30 cm) sur une période de 450 jours. Pendant cette période les éprouvettes étaient stockées à 20 °C et 65 % d'humidité relative. Un béton léger (L), préparé avec des agrégats légers et poreux de deux fractions granulométriques différentes (4 à 8 mm et 0 à 4 mm) et un ciment Portland CEM I 42,5 R, a été comparé avec un béton léger (LZ) préparé avec des agrégats légers et poreux d'une seule fraction granulométrique (4 à 8 mm), un ciment Portland et une mousse spéciale en tant qu'adjuvant ajoutée au mélange de béton. Le béton léger frais (LZ) avec mousse est plus ouvrable et peut être plus facilement compacté que le béton léger (L) sans mousse.

En outre, la structure du béton léger LZ s'est avérée plus uniforme que celle du béton léger L. En ce qui concerne les qualités du béton durci, le béton léger LZ avait, par rapport au béton léger L, une densité à l'état sec inférieure de 11 %, mais une résistance après 28 jours supérieure de 13 %.

Par contre, l'élément de mur en béton léger LZ avec mousse séchait plus lentement et le retrait pour les éprouvettes standard était plus élevé. Le

retrait final déterminé sur les éprouvettes standard était, pour le béton léger LZ, supérieur de 0,16 mm/m à celui béton léger L. Ceci est probablement dû à la teneur en eau plus élevée dans le béton frais avec mousse. Les changements de forme de l'élément de mur en béton léger L étaient terminés après 450 jours. Par contre l'élément de mur en béton léger LZ n'avait atteint que 50 % du retrait final des éléments standard après cette période.

Malgré la différence importante de densité à l'état sec, les deux bétons légers avaient la même conductivité thermique. En conséquence la conductivité thermique spécifique du béton LZ avec mousse était supérieure à celle du béton L.

Les résultats de cette étude montrent qu'une mousse ajoutée en tant qu'adjuvant à un béton léger poreux améliore l'ouvrabilité et produit une structure plus uniforme du béton léger. En outre, l'usage d'une mousse peut, en comparaison avec un béton léger sans mousse, produire une densité supérieure à l'état sec. Par contre, en ce qui concerne d'autres qualités du béton comme p. ex. le retrait, la conductivité thermique et le comportement au séchage, l'influence est plutôt défavorable.

Keywords: lightweight concrete, shrinkage, length changes, drying procedure, foaming agent

1 INTRODUCTION

By the order of the company Lias Tuningen, producer of cellular lightweight aggregates, the Research and Testing Institute of Baden Wurtemberg in Stuttgart investigated the drying behaviour and the length changes of two different lightweight concretes during a period of 450 days.

Through the present study, some knowledge and experiences concerning the effects of using a foam as an admixture upon the drying behaviour and the length changes should be gained.

The following concrete properties were expected to be influenced positively by using the foam:

the reduction of the dry density
the improvement of the drying behaviour
the improvement of the thermal insulating properties
the improvement of the workability of the fresh concrete

the stabilisation of the cement paste in the fresh concrete
the reduction of the drying shrinkage
the increasing of the strength.

The present study compared two different lightweight concretes, called lightweight concrete L and lightweight concrete LZ, made with cellular lightweight aggregates and a Portland cement. In the mix of lightweight concrete LZ, a foam was additionally used. The drying behaviour and the length changes were investigated on wall specimens with a size of 125 cm by 125 cm. The wall specimens had a thickness of 30 cm. The term "length change" as used here is defined as an increase or decrease in a linear dimension on the wall surface of the unloaded wall specimen, which was exposed to the laboratory atmosphere of 20 °C and 65 % relative humidity.

Furthermore both lightweight concretes should be characterised by some hardened concrete tests according to the German DIN standards [1,2,3].

The idea behind the use of a special foam as an admixture was to compare the drying behaviour and length changes of two concretes with different structures. In principle, the special structure of lightweight concrete L and LZ can be imagined to be generated by the close-packing of the coarse grains of the lightweight aggregates, in the present case by the size fraction from 4 mm up to 8 mm. This close-packing of the coarse grains has many voids. In the case of lightweight concrete L these voids are partly filled by both the lightweight aggregates of the fraction from 0 mm up to 4 mm and by the cement paste. Besides, the cement paste envelopes the aggregates and generates a force-transmitting bond between them. In opposite to this, the lightweight concrete LZ doesn't contain any fine lightweight aggregates of the fraction up to 4 mm. The voids are partly filled by the cement paste, which has a cell structure generated by the foam.

Comprehensive reports on the continued investigations on the drying behaviour and the length changes after the age of 450 days and the results of all tests carried out on lightweight concretes L and LZ are given in report 13-18326/3 from 15.12.1995 (up to the concrete age of 589 days) and in report 13-23979 from 01.08.1996 (up to the concrete age of 827 days).

2 CONCRETE MIXES, CURING AND STORAGE

2.1 Concrete Mixes

Table 1 shows the concrete mixes and the properties of the materials used for both types of lightweight concrete.

Table 1. Concrete Mix of the Fresh Lightweight Concrete L and LZ, Related to the Fresh Concrete Batch of 1 m^3

Type	Used Material	Density [kg/dm^3]	Volume [dm^3/m^3]	Amount [kg/m^3]
L	Liapor 3 (4/8)	0,64	652	420
	Liapor SMT (0/4)	1,45	75	109
	Cement CEM I 42,5 R	3,10	65	200
	Water	1,00	111	111
	Air Content	--	97	--
	Total		1000	840
LZ	Liapor 3 (4/8)	0,64	711	458
	Foam SB 31[1)]	--	--	--
	Cement CEM I 42,5 R	3,10	65	200
	Water	1,00	122	122
	Air Content	--	102	--
	Total		1000	780

[1)] Disregarded in the calculation

Four batches of each type of lightweight concrete were used up in the preparation of the wall specimens and of all the standard test specimens.

According to the customer's information both types of cellular lightweight aggregates had an average moisture content about 20 % by mass and were used in the fabrication of fresh concrete without any treatment.

The aggregates of concrete L consisted of the cellular lightweight aggregate type Liapor 3 4 to 8 mm (loose bulk density=325 kg/m³; grain density=0,55-0,65 g/cm³) and of the cellular lightweight aggregate type Liapor SMT for the fraction 0 to 4 mm (loose bulk density = 700 kg/m³, grain density 1,50-1,70 g/cm³). The aggregates of the lightweight concrete LZ only consisted of the cellular lightweight aggregate type Liapor 3.

A Portland cement of the type CEM I 42,5 R according to the German standard DIN 1164 Part 1 (1994) was used.

The foam SB 31 was generated in a special dosing and mixing apparatus before adding to the fresh concrete mix of LZ.

2.2 Wall Specimens

The single wall specimen was 125 cm long, 125 cm high and 30 cm thick. For each lightweight concrete mix, two wall specimens were cast in a special mould, which was placed horizontally on a large compacting platform. After filling the mould the fresh concrete was compacted by vibration. The time of vibration was 20 seconds for the compaction of the fresh concrete L and 10 seconds for the compaction of the fresh concrete LZ. In order to avoid any water evaporation, the surface of the specimens was covered by a plastic foil immediately after compaction. The four specimens were stored, protected against any shakings.

2.3 Standard Test Specimens

For the standard tests, cubes (200 mm x 200 mm x 200 mm), cylinders (∅ 150 mm; h = 300 mm) and beams (530 mm x 100 mm x 100 mm) were fabricated. For the various standard test specimens the fresh concrete of the same batches as for the wall specimens was used. The fresh concrete in the moulds was compacted by vibration for 20 seconds in case of concrete L, and for 10 seconds in case of concrete LZ. The moulds were covered by a plastic foil.

2.4 Demoulding and Preparation

At the concrete age of three days, the standard specimens were demoulded and stored in clime conditions of 20°C and 95 % relative humidity. At the age of 8 days, they were stored at a laboratory atmosphere, as demanded by the corresponding test standard [1,2,3].

At the age of 3 days, the cast planks of the four wall specimens were removed. The wall specimens were enveloped in a plastic foil. At the age of 8 days, they were unpacked again and stored in an upright position in a room with a constant atmosphere of 20 °C and 65 % relative humidity

In order to generate the relations of a larger wall unit in length and in height, the four smaller sides of each wall specimen were sealed by two different thin surfacings. The lower material consisted of a fine mortar, which was covered by a bitumen coat. Thus, the wall specimens could mainly loose their moisture by the wall sides.

3 CONCRETE PROPERTIES

The results of the various tests carried out according to German standards [1,2,3] are shown in table 2 for both types of lightweight concrete.

Though the density was reduced by the use of the foam, the strength properties of the lightweight concrete LZ improved. In opposition to that, the thermal conductivity remained constant. The higher amount of the final shrinkage of lightweight concrete LZ is likely to be caused by the bigger moisture content.

Table 2. Test Results of the Fresh and Hardened Concrete (Average Values)

Test	Unit	Lightweight Concrete L	Lightweight Concrete LZ [1)]
Fresh Concrete Density	kg/dm^3	0,85	0,78
Hardened Concrete Density, Dry	kg/dm^3	0,73	0,65
7-Day-Compressive Strength	N/mm^2	3,5	4,3
28-Day-Compressive Strength	N/mm^2	4,6	5,2
28-Day-Flexural Strength	N/mm^2	1,2	1,5
28-Day-Splitting Tensile Strength	N/mm^2	0,7	0,8
Static Modules Of Elasticity By Compression	N/mm^2	3400	3000
Thermal Conductivity, Dry [2)]	W/mK	0,175	0,174
Final Shrinkage Rate [3)]	mm/m	0,61	0,77

1) prepared with foam SB 31
2) test specimens 500 mm by 500 mm by 50 mm
3) cylindrical standard test specimens (Ø 150 mm; h = 300 mm)

4 DRYING BEHAVIOUR OF THE WALL SPECIMENS

The moisture content was determined on the wall specimens made of the lightweight concrete L and LZ in form of a profile in the direction of the wall thickness. The moisture content was determined at the concrete age of 9 days, 30 days, 90 days, 360 days and 450 days.

In two different places, a core of 30 cm length was drawn and divided into 5 cylindrical parts, each of about 6 cm length. The bore holes were closed again. The parts of the drilled core were dried at 105°C to constant mass.

The graph of the moisture contents in the different segments of the wall are shown in figure 1 and in figure 2.

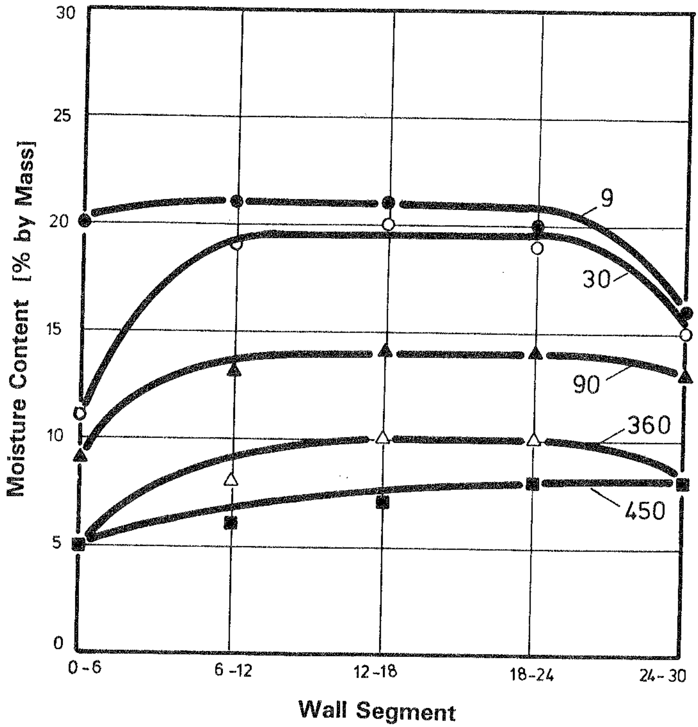

Figure 1 Wall Profiles of the Moisture Content in the Different Segments of Lightweight Concrete L as Function of the Concrete Age; Storing Condition: T=20°C, rH = 65 %

The moisture content of lightweight concrete of this type after reaching the balanced state to the environment is 4 % by volume according to the German standard DIN 4108 part 4 [4]. That corresponds to 5 % by mass for a dry density of 0.8 kg/dm³.

At the age of 9 days, the lightweight concrete L had an average moisture content of 19 % by mass. The moisture content was reduced to 8 % by mass at the age of 360 days, and to 7 % by mass at the age of 450 days. After this

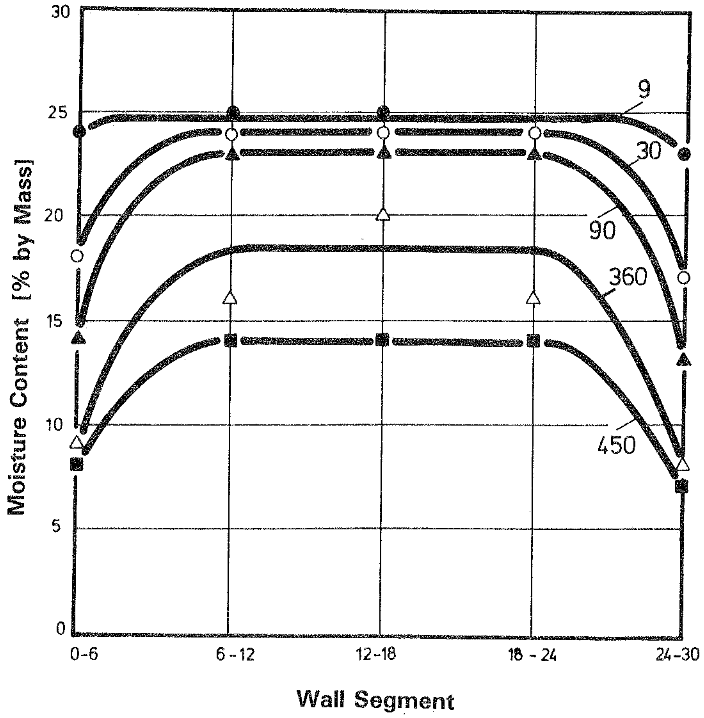

Figure 2 Wall Profiles of the Moisture Content in the Different Segments of Lightweight Concrete LZ as Function of the Concrete Age; Storing Condition: T=20°C, r.H. = 65 %

period of time the moisture content had almost reached the moisture equilibrium with the environment. In opposition to this, the initial moisture content of the lightweight concrete LZ was 24 % by mass in average, decreasing to 14 % by mass at the age of 360 days and to 11 % by mass at the age of 450 days. Up to this concrete age, the moisture content was still twice as high as the moisture content published in the DIN standard 4108 part 4.

5 LENGTH CHANGES ON THE WALL SPECIMENS

The length changes of the wall specimens while storing in the atmosphere of 20°C and 65 % relative humidity were measured at the age of 9 days, 30 days, 90 days, 360 days and 450 days. The observed length changes were mainly due to the drying shrinkage of the wall specimens. For the measuring of the length changes, vertical and horizontal gage lines were fixed on the surface of each side of the wall specimen. The length of each gage line was 50 cm. In one direction two gage lines completed to one meter. The cross point of these measurement lines was in the centre of the wall side.

Besides, the length changes were determined on cylindrical standard test specimens stored at 20 °C and 65 % relative humidity.

The graphs of the length changes measured on each side of the wall and of the drying shrinkage of standard specimens are given in figure 3 for lightweight concrete L and in figure 4 for lightweight concrete LZ.

On the base of the average final shrinkage value, which was determined on the small cylindrical test specimens, the following statements can be made concerning the procedure of the length changes recorded on the wall specimens made of the lightweight concrete L and LZ, respectively.

At the age of 450 days, both sides of the wall specimen made of lightweight concrete L reached the final measure of length change of the corresponding standard test specimens (0,6 mm/m). In opposition to this, the length changes for both sides – upper fabrication side: 0,48 mm/m; lower fabrication side: 0,24 mm/m – of wall specimen LZ were significantly smaller than the final value of the cylindrical test specimens (0,8 mm/m).

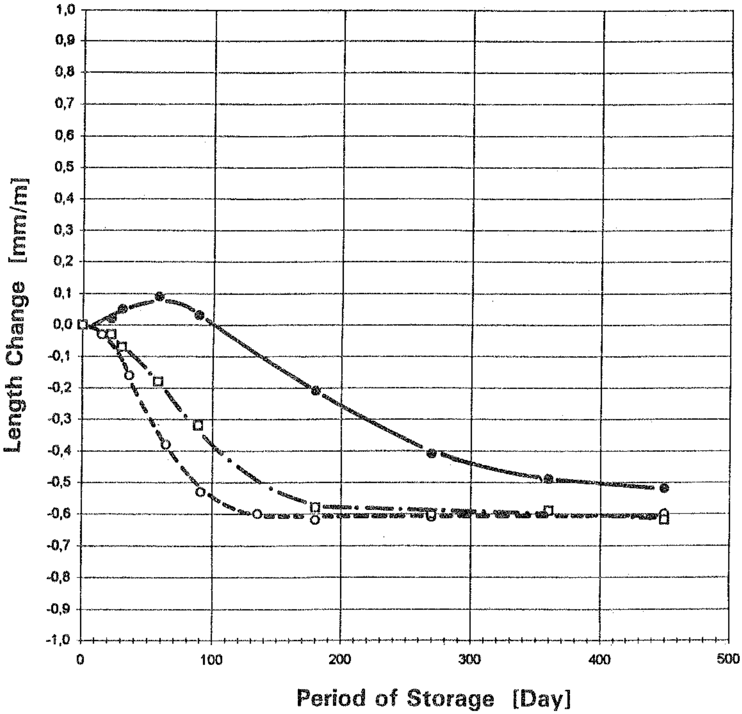

Figure 3 Length Changes of the Wall Specimen L
Storing Condition: T=20 °C, rH= 65
Key: Upper Fabrication Side
Lower Fabrication Side
Standard Test Cylinder

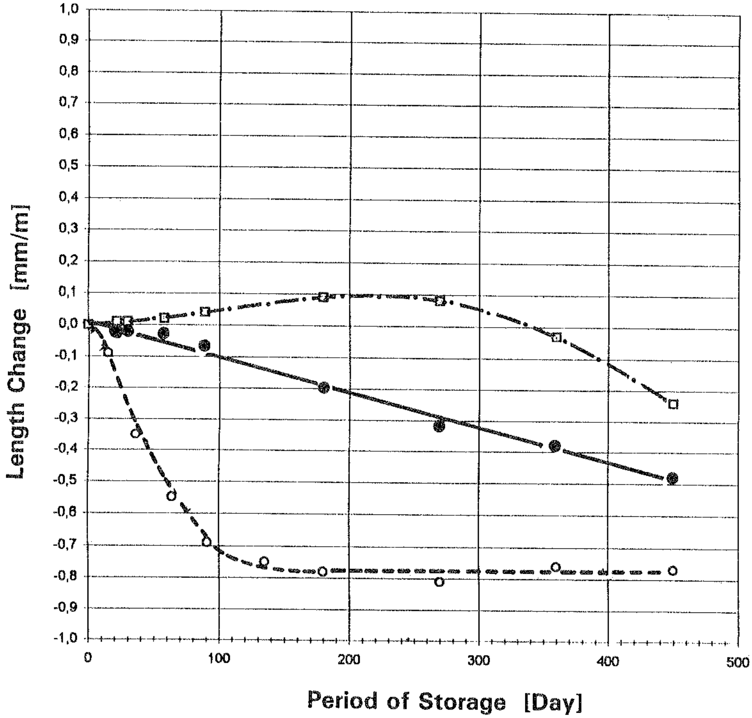

Figure 4 Length Changes of the Wall Specimen LZ
Storing Condition: T=20 °C, rH= 65
Key: ——— Upper Fabrication Side
– - – - – Lower Fabrication Side
- - - - - Standard Test Cylinder

6 CONCLUSION

The workability of the fresh concrete could distinctly be improved by the use of a foam. Furthermore, the lightweight concrete with foam had a more homogenous structure and a more homogenous density. However, the foam could not completely prevent the segregation by gravity among the aggregates and the cement paste. Consequently, the quality of the upper fabrication surface and of the lower fabrication surface were different, too.

Contrary to the general relation of density and strength or density and thermal conductivity, the lightweight concrete with foam comparatively had both a higher strength and a higher thermal conductivity.

The drying rate of the lightweight concrete with foam was reduced compared with the corresponding lightweight concrete without foam, especially the moisture migration out of the inner wall segments to the outer segments proceeded very slowly. This circumstance could be connected with the specific structure, which was generated in the cement paste by the foam.

The length changes of both types of lightweight concrete, caused by the drying procedure, were different. At the age of 450 days the lightweight concrete prepared without foam had reached largely the average final value of shrinkage determined on standard test specimens. On the contrary, the shrinking of the wall specimens prepared from the lightweight concrete with foam had proceeded in smaller steps and, at the age of 450 days, reached only 50 % of the average shrinkage value measured on the test cylinders.

7 REFERENCES

[1] German standard DIN 1048 part 1 -Testing methods for concrete; fresh concrete- (1991)

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[4] German Standard DIN 4108 part 4 -Thermal insulation in buildings; characteristic value relating to thermal insulation and protection against moisture- (1991)