SOME TESTS ON CREEP AND SHRINKAGE OF RECYCLED LIGHTWEIGHT AGGREGATE CONCRETE

EINIGE KRIECH- UND SCHWINDVERSUCHE AN REZYKLIERTEM LEICHTBETON

QUELQUES ESSAIS SUR LE FLUAGE ET LE RETRAIT DU BETON LEGER RECYCLE

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SUMMARY

Tests have been performed on four concrete mixtures made with aggregates originating from crushed lightweight aggregate concrete. The water-cement ratio and the amount of recycled aggregates were varied. Two mixtures contained natural sand while two other mixtures did not. The results show the expected influence of water-cement ratio on strength, stiffness, shrinkage and creep. The higher the amount of recycled aggregates, the lower are strength and stiffness and the higher are shrinkage strain and creep.

ZUSAMMENFASSUNG

An vier Betonen mit rezykliertem Leichtbeton wurden Kriech- und Schwindversuche durchgeführt. Wasserzementwert und Rezyklatmenge wurden variiert. Zwei Betonzusammensetzungen enthielten Natursand, zwei nicht. Die Ergebnisse zeigen den erwarteten Einfluß des Wasserzementwerts auf Festigkeit, Steifigkeit, Schwinden und Kriechen. Je höher der Rezyklatanteil ist, umso niedriger sind Festigkeit und Steifigkeit und umso höher sind Schwinden und Kriechen.

RESUME

Des essais de retrait et de fluage ont été réalisés sur quatre bétons contenant des agrégats de béton léger recyclé. Nous avons varié le rapport eau/ciment et la teneur en agrégats recyclés. Deux des quatre compositions contenaient du sable naturel. Les résultats montrent l'influence prévue du rapport eau/ciment sur la résistance, la rigidité, le retrait et le fluage. Une augmentation de la teneur en agrégats recyclés mène à une diminution de la résistance et de la rigidité, ainsi qu'à une augmentation du retrait et du fluage.

1. INTRODUCTION

A large cooperative research project was carried out which was aimed at the investigation of demolition techniques of structures and the reuse of mineral materials and which was called life cycle of materials in concrete construction [in German: Baustoffkreislauf im Massivbau, BiM]. Within this framework, a project dealt with recycling of lightweight aggregate concrete. The question arose whether normal crushing techniques were able to produce a material which could be reused in concrete and not a material which consisted mainly of dust and fines. A second question concerned the deformation properties of concrete made out of crushed lightweight aggregate concrete. Some experiments were carried out which are described and discussed in the following.

2. MATERIALS

Since there was no chance to receive lightweight aggregate (LWA) concrete from a demolition site it was decided to produce a LWA concrete. The primary concrete consisted of expanded clay aggregates (Liapor G6 4/16), quartz sand 0/4, CEM I 42.5 R and a water-cement ratio of 0.56. The compression strength corresponded to a LC 30/33 and a density class of D1.6 (prEN 206). After 6 to 12 months, the concrete was crushed in a three step procedure. First, a jaw breaker crushed the concrete slab into pieces with a diameter > 45 mm. Second, these pieces were fed into a rebound crusher.

A rebound crusher produces rather cubical grains opposite to a jaw breaker which produces more flaky and elongated material. After sieving, the grains larger than 16 mm were crushed again in a rebound crusher. The resulting fraction 4/16 mm is shown in Fig. 1.

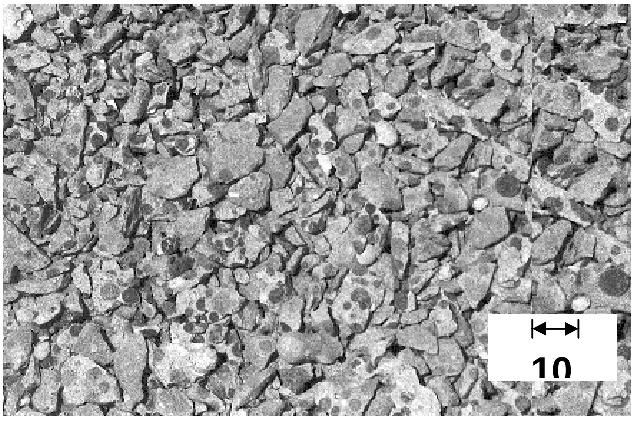

Fig. 1. *Crushed lightweight aggregate concrete particles of size 4/16 mm*

It can be seen that the shape is very appropriate and that the surface is rather smooth.

The crushed LWA concrete was available in the grain size fractions 0/4, 4/8 and 8/16 mm. Some properties are given in Table 1.

Table 1. *Properties of crushed LWA concrete aggregate*

Aggregate fraction mm	Apparent density kg/m^3	Bulk density kg/m^3	Capillary water absorption after 10 min. % by mass
0/2	1760	} 980	} 16.0
2/4	1650		
4/8	1640	840	13.2
8/16	1690	849	11.7

The density varies between 1640 and 1700 kg/m^3 although there is no clear trend with respect to grain size. Original lightweight aggregate tends to lower density with increasing size which is the result of larger porosity in lager grains. However, cement paste and natural sand particles adhere to the crushed LWA concrete grain which causes various mixtures of particles.

German practice is to account for the 30 minutes water absorption in the mix design. After 30 minutes, there is only little more water absorbed.

When natural sand is used it is a quartzitic material of rounded shape with a density of 2630 kg/m^3. An ordinary portland cement CEM I 32.5 R has been used throughout the tests.

3. FRESH CONCRETE

Four mixes were designed which allowed two water-cement ratios and two aggregate compositions. The workability should be around 40 cm measured on the flow table according to DIN 1048. Table 2 shows the composition of the mixtures and Table 3 the properties of the fresh concrete.

Before mixing the recycled aggregates 4/8 and 8/16 were wetted by immersion during 15 minutes. The aggregates were then removed from the water and air dried until the surface was mat. The mixing procedure followed always the same sequence, i.e. aggregates plus two third of the water were mixed during 60 sec., stand still during 120 sec., adding of cement and the remaining water and another 90 sec. mixing. The specimens were demoulded after one day, then stored in a fog room for 6 days, and stored in a climate controlled room (20°C, 65% RH) until the 28th day. After 28 days, the creep specimens and companion shrinkage specimens were moved to a room with partial climate control.

Table 2. *Composition of the mixtures*

Component	Unit	Mixture			
		I	II	III	IV
Cement content	kg/m^3	240	240	350	350
Water content [1)]	kg/m^3	144	144	175	175
Water-cement ratio [2)]	-	0.60	0.60	0.50	0.50
Natural sand					
Fraction 0/0.6 mm	kg/m^3	321	-	294	-
0.6/2 mm	kg/m^3	350	-	321	-
2/4 mm	kg/m^3	273	-	249	-
Recycled LWA concrete					
0/2 mm	kg/m^3	-	432	-	395
2/4 mm	kg/m^3	-	186	-	171
4/8 mm	kg/m^3	281	281	257	257
8/16 mm	kg/m^3	421	421	386	386
$\frac{\text{Recycled aggregate}}{\text{Total aggregate}}$	% by vol.	54	100	54	100

[1)] Effective water, i.e. total water minus absorbed water during 30 minutes
[2)] Effective water-cement ratio

Table 3. *Properties of fresh concrete*

Property	Unit	Mixture			
		I	II	III	IV
Consistence [1)]	cm	37	35	40	46
Fresh density	kg/m^3	2020	1820	2050	1850
Air content [2)]	% by vol.	4.5	3.7	2.8	2.7

[1)] Measured on flow table acc. to DIN 1048
[2)] Measured by pressure method acc. to DIN 1048

4. HARDENED CONCRETE

One of the features of lightweight concrete is the dry density. This has been determined on 28 days old specimens by drying at 105°C until constant mass. The compressive strength has been measured on 100 mm cubes. Young´s modulus has been calculated from the increase of strain due to an increase of stress up to one third of the nominal failure load of a 100 mm wide x 300 mm long cylinder at 28 days. Table 4 shows the results as mean of three single values.

Table 4. *Properties of hardened concrete*

Property	Unit	Mixture			
		I	II	III	IV
Dry density	kg/m^3	1860	1520	1900	1580
Density class [1)]	-	D2.0	D1.6	D2.0	D1.6
Moisture content [2)]	% by vol.	6.7	11.9	7.4	12.5
Compressive strength [3)]	MPa	29.2	15.2	37.6	30.6
Strength class [1)]	-	LC 20/22	LC12/13	LC30/33	LC20/22
Young´s modulus	GPa	19.5	9.3	21.6	14.6

[1)] According to prEN 206
[2)] Calculated from weight loss during drying
[3)] 100 mm cubes

5. DEFORMATION OF HARDENED CONCRETE

The deformation of a non-loaded specimen is due to shrinkage and thermal movement. A loaded specimen shows additional elastic and creep deformation.

5.1 Shrinkage

Shrinkage was measured on 100 mm x 300 mm cylinders with a gage length of 200 mm. Three measuring lines were positioned on 120 degree which allowed the calculation of a mean value and the determination of excentric movement. Fig. 2 shows the measured strain as function of time starting at an age of 1 day, i.e. immediately after demoulding. The specimens were stored in a fog room with nearly 100% RH during 6 days and moved to a climate controlled room (65% RH) for the subsequent time. It can be seen that all specimens increased their length during the time in the fog room. Those made out of 100% recycled aggregates increased the length by about 0.25 mm/m while the ones with 54% recycled aggregates increased by about 0.18 mm/m. Concrete with more cement and a lower water-cement ratio expanded less than the mixture with less amount and a higher water-cement ratio.

Between 15 and 20 days, all concretes started to shrink. There is a significant difference between concrete with 100 and 54% recycled aggregates and there is almost the same shrinkage irrespective of the cement content and water-cement ratio.

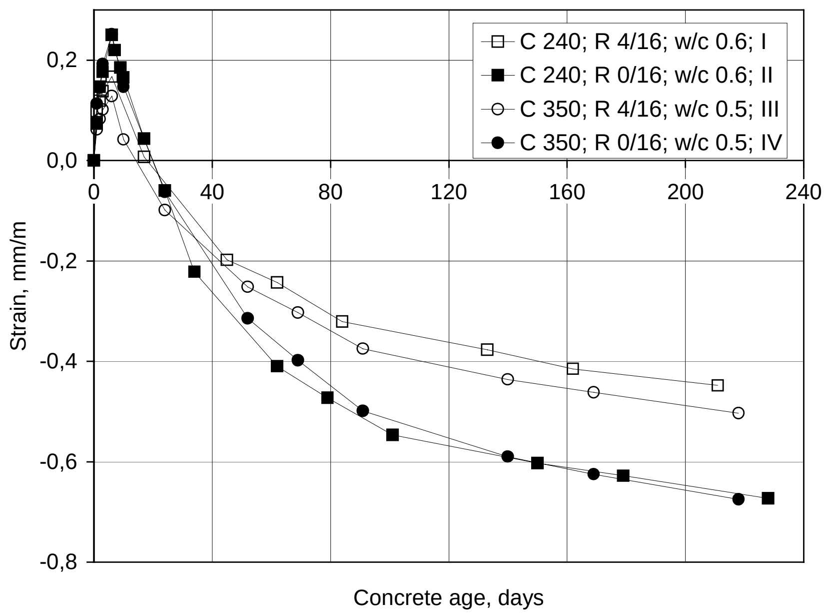

Fig. 2. *Shrinkage as function of time*

5.2 Creep

The cylinders were loaded to one third of the nominal strength at an age of 28 days. The total strain was measured by three dial gauges mounted on the cylinder surface. The gauge length was 200 mm. Fig. 3 illustrates the components of total strain of a specific test (Mixture II) until 65 days of loading. The elastic part is assumed constant, i.e. the continuous hydration and increase of stiffness is not taken into account.

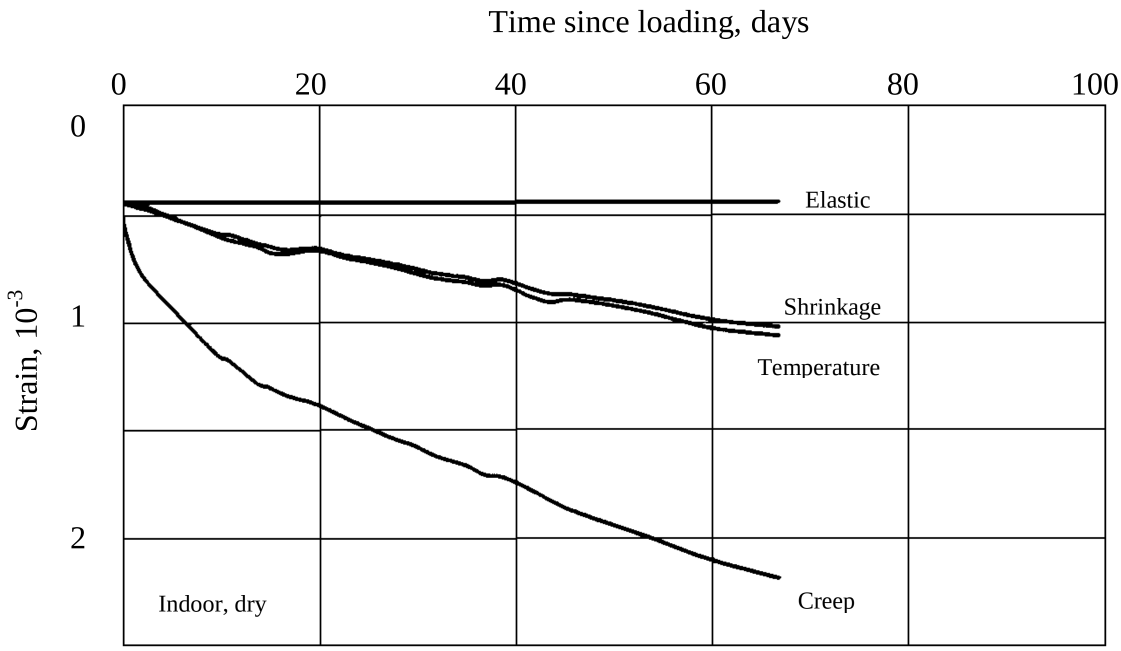

Fig. 3. *Components of total strain*

Shrinkage is measured on companion specimens in the creep room. Temperature fluctuations were measured and calculated with a coefficient of thermal expansion equal to $9 \cdot 10^{-6}$ K^{-1}. Finally, the remaining strain is attributed to creep not distinguishing between basic creep and drying creep. The tests have been continued until almost 300 days. The results are shown in Fig. 4. It is obvious that the concretes with 100% recycled aggregates creep more than the concretes with only 54% recycled aggregate do. A higher water-cement ratio leads to higher creep which is confirmed by the difference of creep of mixtures II and IV and I and III.

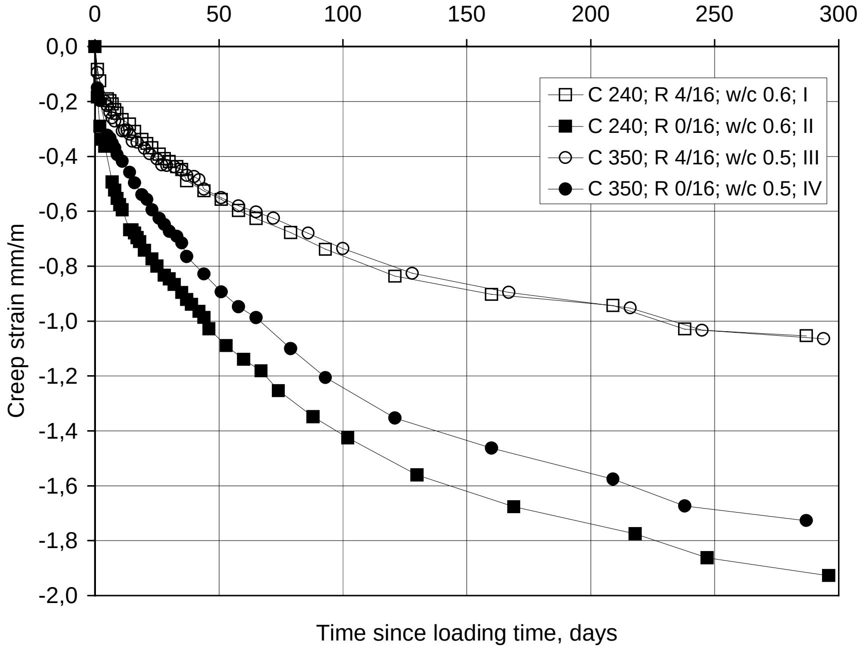

Fig. 4. *Creep strain vs. time since loading*

6. DISCUSSION OF RESULTS

6.1 Shrinkage

The discussion will be confined to shrinkage and creep aspects. Shrinkage can have various causes. Autogeneous shrinkage results from the volume reduction of water when it is chemically bound. However, the water-cement ratios are in such a range that there is enough water available even at complete hydration, i.e. no self-desiccation will occur. Plastic shrinkage (or capillary shrinkage) can occur when the surface of young concrete dries out which produces tensile stresses reaching the current tensile strength. This phenomenon is prevented by moist curing. Carbonation shrinkage takes more time than allowed in the test, i.e. the carbonation of a thin surface layer of the specimen can only produce negligible carbonation shrinkage. What remains is drying shrinkage which is a consequence of water loss and densification of the hydrated cement paste.

Fig. 5 shows the mass changes as function of time. All four concretes increase their weight during storage in the fog room by about 1% by mass. This means that there is a moisture gradient from the moist air to the pore humidity of the concrete. There are two possible reasons. First, the lightweight aggregates have absorbed water from the cement paste and the cement paste has taken water up from the air. This should result in a small volume decrease due to shrinkage of the paste which may be compensated by the water absorption from the air. Second, the hardened cement paste of the recycled LWA concrete has absorbed water from the new cement paste or the moist air and has swollen. This second assumption seems appropriate because it has increased in mass as seen from Fig. 5 and in volume as seen from Fig. 2.

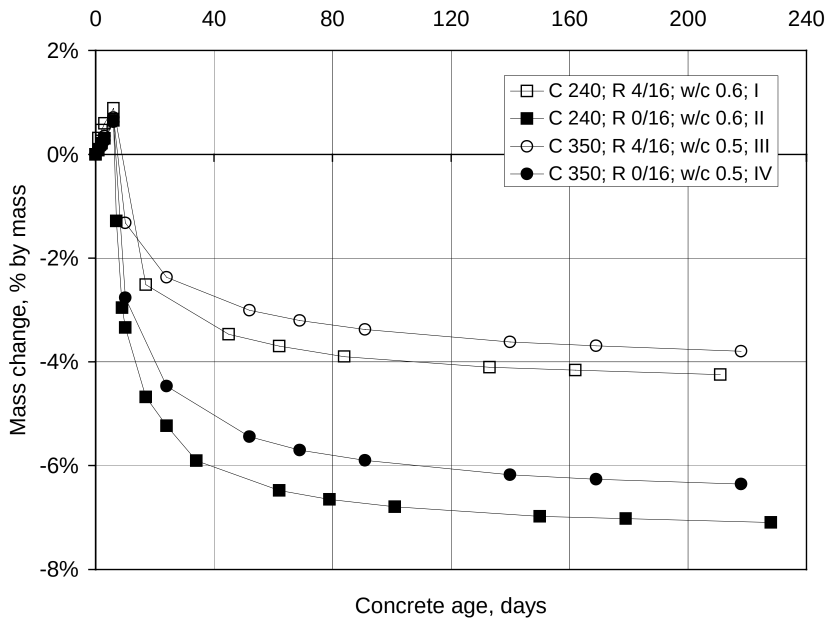

Fig. 5. *Mass change vs. time*

Comparing Fig. 2 and Fig. 5 yields that the maximum expansion coincides with the maximum mass increase which happens after 6 days. The exposure in 65% RH causes immediate drying and the mass gain is equilibrated after about 1 day.

However, shrinkage is delayed and only, after another 10 to 14 days, the length has reached the initial length again. This means that the component which can shrink, i.e. the hydrated cement paste, is still water saturated although the overall water content has decreased. It is assumed that water can be absorbed from the lightweight aggregate while the surface of the specimen is drying out. A flow of moisture is taking place from the aggregate to the hydrated cement paste (HCP) because the HCP has smaller pores than the LWA.

To show the relation between moisture change and strain Figs. 2 and 5 are combined to one graph in Fig. 6. There are four stages to be distinguished. Stage one is situated in the upper right quadrant with increasing mass and increasing length. When drying starts the mass decreases while the strain is lagging behind. When $\varepsilon_s = 0$ is reached the mass decreases only slowly but shrinkage starts. Finally the shrinkage rate increases once again. These four stages occur for concrete with 54% recycled aggregates and even more pronounced for concrete with 100% recycled aggregates. The four stages are qualitatively related to the four phenomena: water absorption of hydrated cement paste adhering to the crushed LWA concrete grains, evaporation of water and emptying of pores of LWA, shrinkage of old and new paste at high RH due to emptying of large capillary pores, and finally shrinkage of HCP at low RH due to evaporation of physically bound water.

This typical behaviour is an obvious feature of all four concrete mixtures which contain crushed LWA concrete as recycled aggregate.

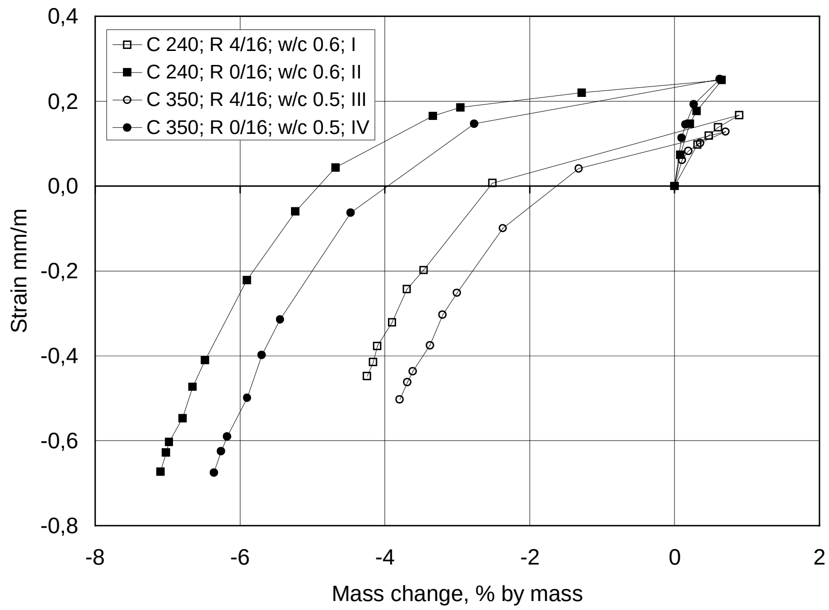

Fig. 6. *Strain vs. mass change during 230 days*

6.2 Creep

The creep test started only at an age of 28 days, i.e. moisture movement and drying shrinkage had already taken place for a great deal. As Fig. 4 shows there is continuous creep up to 300 days. The creep compliance function is given by

$$J(t,t_0) = \frac{1}{E(t_0)} + C(t,t_0) \qquad (1)$$

with E (t_0) = Young´s modulus characterizing the instantanous deformation at age t_0 and C (t, t_0) = creep compliance or specific creep. Eq. (1) is synonymous with the following

$$J(t,t_0) = \frac{1+\varphi(t,t_0)}{E(t_0)} \qquad (2)$$

with φ (t, t0) = creep coefficient which is equivalent to E (t0) · J (t, t0) - 1 or the ratio between creep deformation to instantanous deformation.

Total strain minus shrinkage and thermal strain is given by

$$\varepsilon(t) = J(t, t_0)\,\sigma \tag{3}$$

Fig. 7 shows the relation between J (t, t_0) and time since loading. J (t, t_0) increases more with a larger amount of recycled aggregates and with higher water-cement ratio.

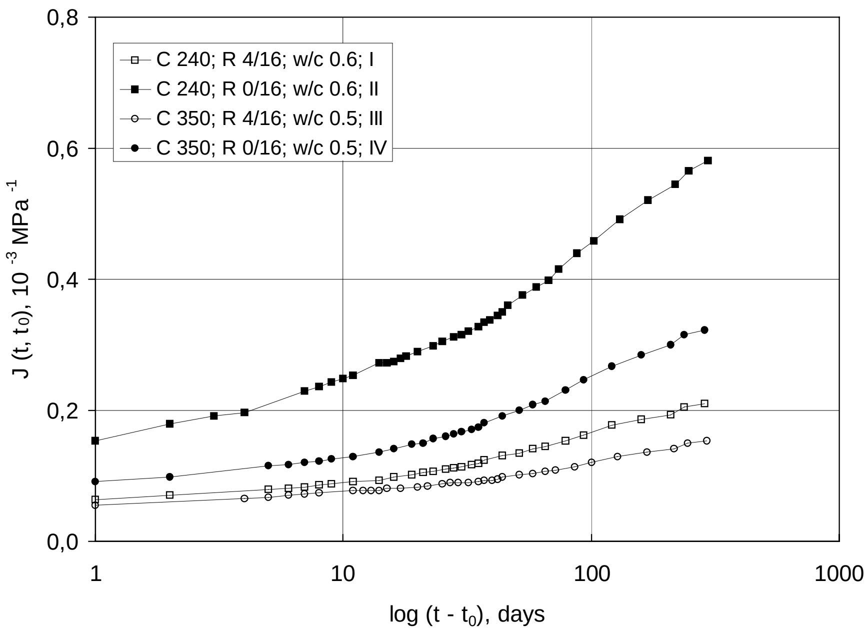

Fig. 7. *Creep compliance function vs. time since loading*

While concrete with 54% recycled aggregates show a compliance which is in the same order of magnitude like primary concrete, i.e. without recycled aggregates, concrete with 100% recycled aggregates shows considerable more creep and elastic strain.

7. CONCLUSIONS

The main results of the limited investigations are:

- It is possible to crush lightweight aggregate concrete such that it can be reused as aggregate
- Concrete made of such recycled aggregates reaches a low to moderate strength depending on cement content and water-cement ratio
- The secondary concrete is a lightweight concrete again
- Shrinkage is depending on the amount of recycled aggregates used, it is about 50% more for concrete with 100% recycled aggregates compared to concrete with 54% recycled aggregates.
- Creep is also strongly affected by the amount of recycled aggregate.

The interaction of water and swelling and shrinkage is a phenomenon which deserves more research.

8. ACKNOWLEDGEMENT

The authors like to acknowledge the contribution by S. Pohl and B. Rehm who prepared their diploma thesis (Diplomarbeit) within BiM. The cooperation with Liapor Franken is greatfully acknowledged.

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