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Effect of the addition of ultrafine cement and short fiber reinforcement on shrinkage, rheological and mechanical properties of Portland cement pastes

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Abstract

The packing density of a powder can be improved by adding a fine powder to a coarse one. This conventional technique, frequently used in ceramic production, also can be applied to optimise the properties of cementitious binders, especially for the production of high performance concrete. In this paper the effect of mixing ultrafine cement and normal grain sized Portland cement is studied.

The rheological properties of the fresh paste are influenced positively. An important dispersing effect is observed, decreasing yield value and plastic viscosity. This permits mixing of very low w/c-ratio cement pastes with low porosity and high strengths, applying conventional mixing procedures.

Due to the low amount of water, that is available in the narrow pores, the hydration of the cement is not complete. At the same time, permeability is strongly reduced, leading to a lack of water with ongoing hydration. Self-desiccation especially at early age is the consequence. Shrinkage and as a consequence crack formation may be observed.

In a special experimental setup early shrinkage (from nearly time zero after mixing) was monitored continuously. Fresh pastes of different mix proportions were put in a cone and the length change was measured by a laser system. Additionally, the shrinkage of hardened pastes was measured until 90 days by conventional technique. The influence of different surrounding climates was studied.

Such dense materials generally are very brittle. The use of fibers increases the ductility significantly and leads to a further improvement of the shrinkage and strength properties. The excellent rheological properties of the cement matrix containing ultrafine cement also allows a conventional mixing of composites with a high fiber content. The effect of different amount and type (PP, carbon) of fibers on the shrinkage at very early age and the influence of different curing conditions at early age on the mechanical properties was studied.

Keywords: Ultrafine cement; Packing density; Fiber; Early age shrinkage; Mechanical properties; Rheology

1. Introduction

Gas and water transport, frost resistance and therefore durability as well as shrinkage and mechanical properties of cementitious building materials are influenced by the porosity. For instance when the cement paste is pressed during setting, a far reduced porosity results which leads to a very high compressive strength [1]. Porosity widely depends on the chemical composition of the raw materials, their hydration processes and the packing properties of the different components (sand, cement, filler). Packing density may be increased combining two or more components with different particle size distribution [2]. New concrete mix designs like densified small particles (DSP) are based on this concept. They involve a dense granular matrix with high superplasticizer and silica fume content and extremely hard aggregates (granite, calcined bauxite etc.) [3].

Curing conditions at very early age considerably influence the performance of cement-based building materials. Drying hinders hydration process and the induced shrinkage leads to damage of the microstructure. Later addition of water is not able to heal this damages and re-initiated hydration causes internal stress and loss of mechanical properties [4]. If the autogenous shrinkage is confined externally, the concrete is

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subjected to a tensile load leading to crack formation. Tensile creep [5] may mitigate part of this tensile stress. Silica fume markedly increases autogenous shrinkage. Jensen [6] suggests from experiments with different amounts of microsilica, that the observed autogenous relative humidity change is due to self-desiccation and the presence of dissolved salts. The deformation after setting is attributed to self-desiccation shrinkage and shrinkage due to microstructural disappearance of a restraining component.

Due to the susceptibility to shrinkage of binder systems containing silica fume, a concept replacing silica fume by ultrafine cement and/or puzzolanic active or inert fillers was tested. The effect of microfillers on enhancement of concrete strength and fluidity has been demonstrated [7–9]. Different amounts of ultrafine cement and filler were added to ordinary Portland cement. A conventional mixing process was used. The application of superplasticizers allowed the preparation of cement slurries and mortars with very low water–cement ratio. Mechanical and rheological properties and length change of these binder systems were studied.

2. Experimental

2.1. Composition of cement and filler

Portland cement CEM I 42.5 N according to European Standard EN 197-1, ultrafine cement (Portland cement blended with blastfurnace slag) and limestone filler were used as part of the binder system. The chemical composition of the cementitious binder compounds are given in Table 1. Fig. 1 shows the particle size distributions obtained by laser diffraction. As water-reducing agent a superplasticizer (polycarboxylate type) was used. The pastes were prepared using a mortar mixer (EN 196-1) at 62.5 rpm.

2.2. Rheology

In a first test series, cement pastes were prepared with different fillers—ultrafine cement, microsilica, metakaolin and limestone filler. The water/binder-ratio was 0.20%, and 2.0% superplasticizer referred to the binder was used.

For the rheological measurements a rheometer in controlled shear rate mode was used. It was equipped

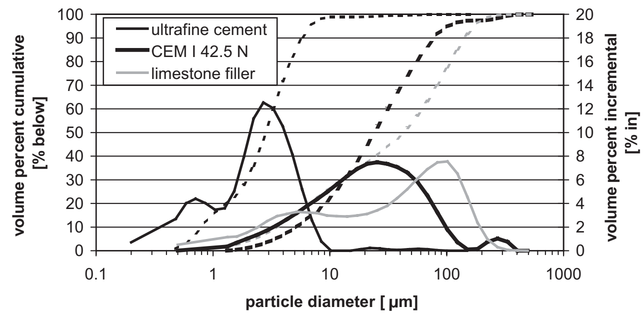

Fig. 1. Particle size distribution of raw materials.

with a spherical measuring system, developed especially for cement pastes and mortars [10]. Instead of a laminar flow, as for example in cylindrical geometry, a displacement flow is caused by a sphere rotating concentrically around the test system axis. This kind of measuring system has several advantages compared to conventional systems (e.g. cylinder or plate–plate), when used for building materials: wall slip and sedimentation are minimized, the examination of mortars up to an aggregate grain size of about 4 mm is possible.

The pastes were mixed as described above. Water/binder ratio was 0.20. Immediately after mixing a flow curve with shear rates from 0.01 to 100 s^{-1} was recorded. Apparent yield stress and plastic viscosity were derived from the flow curve according to the Bingham model. Fig. 2 shows the results.

Pure Portland cement paste shows a yield value of 129 Pa and a viscosity of 105 Pa s. The replacement of up to 20% Portland cement by ultrafine cement leads to

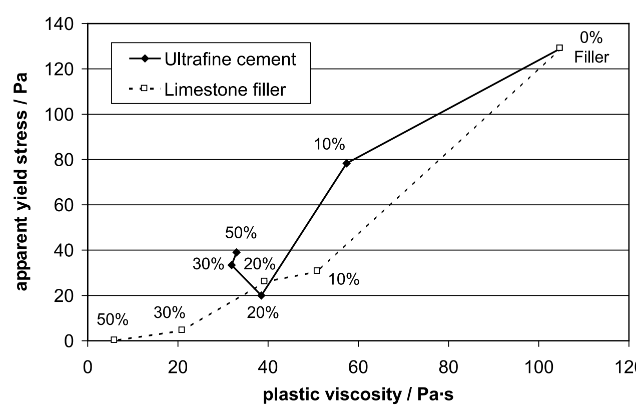

Fig. 2. Bingham parameters of the investigated cement pastes with different filler contents.

Table 1
Chemical composition of the cements used

	CaO (wt.%)	MgO (wt.%)	SiO_2 (wt.%)	Al_2O_3 (wt.%)	Fe_2O_3 (wt.%)	Na_2O (wt.%)	K_2O (wt.%)	SO_3 (wt.%)	L.O.I. (wt.%)
CEM I 42.5	62.8	2.0	19.9	5.4	2.8	0.13	1.0	2.8	2.5
Ultrafine cement	45.3	8.1	32.6	9.9	0.6	0.3	0.4	2.6	1.5

a decrease both in yield value and in viscosity. Higher dosages of ultrafine cement cause an increase in yield stress and in viscosity, so the dosage of 20% can be seen as the optimum with a yield value of 20 Pa and a viscosity of 39 Pa s. The slump flow of this mixture also shows an optimum with 305 mm compared to 235 mm for the pure cement paste. Dosages of ultrafine cement above 50% could not be examined because of their poor workability.

The combination of the ultrafine cement with Portland cement leads to a bimodal grain size distribution. Because the packing density is improved, the paste shows a better workability at the same water/binder ratio. The optimum is a content of 20% ultrafine cement, that seems to be the right amount to fill the voids between the cement grains. Otherwise it is possible to reduce the w/b-ratio by partial replacement of Portland cement without loss of workability.

The limestone filler shows a complete different behavior. Increasing limestone content in the binder decreases both yield value and viscosity, no minimum can be observed. The limestone filler shows a bimodal particle size distribution with two maxima at about 100 and 5 μm. This might be favourable to increase packing density. Additionally limestone filler is hydrophobe. This might explain the good workability and the lack of an optimum in limestone dosage. Microsilica and calcined china clay (not shown in Fig. 2) however lead to an increase in yield value and plastic viscosity and to a decrease in slump flow.

2.3. Early age shrinkage

Because of its importance for early age crack formation, shrinkage was measured in different ways. First very early shrinkage from nearly time zero was registered. The expansion in the first minutes and hours after start of mixing is registered touch-less and very exact by a laser beam. A reflector plate is slightly pressed into the fresh paste. There is no mechanical coupling between the fluid and the sensor necessary. To ensure that the length change is not hindered in one dimension, a special formed specimen container in the form of a cone is used. Volume change hence is proportional to the power 3 of length change. The length change is registered with a resolution of 0.1 μm. Synchronously with the length change, specimen and air temperature are registered. For specimen temperature measurement, a Pt 100 thermocouple was placed into a glass tube filled with oil. A temperature correction of the measured length change was carried out, however the contribution of thermal expansion to the measured length changes was small. The whole apparatus was placed in a clime chamber so that the relative humidity and the air temperature could be kept constant (Fig. 3).

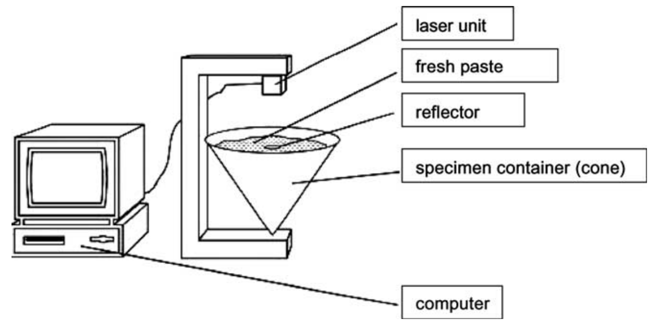

Fig. 3. Test arrangement for measurement of early age shrinkage.

In this way autogenous shrinkage at different relative humidity conditions can be measured. The whole system is a semi-adiabatic measurement arrangement. The big lack of this method is that neither chemical shrinkage (e.g. self-desiccation) [11,12] nor creep [5] nor stress [13,14] can be monitored. The big advantage is, that the behavior of mortar at different surrounding climates almost from time zero after mixing can be studied. The surrounding relative humidity was adjusted to 98% (at 20 °C over saturated K_2SO_4 aqueous solution) and 75% respectively (at 20 °C over saturated NaCl aqueous solution).

Cement pastes were prepared as described above with different fillers-ultrafine cement, microsilica and limestone filler. Time zero in the plots means start of mixing. After 7 min approximately, the fresh paste was placed and the measurement was started. Length change at this time was set to zero.

Fig. 4 shows the length change and temperature behavior of pastes made of pure Portland cement. The lower w/c-ratio (0.19) was achieved adding 2 wt.% of superplasticizer. Sample temperature is higher the first minutes owing to ettringite formation [15,16] and hydration of sulfate carrier, dissolution of ions and mixing energy. Then temperature drops during the dormant phase of hydration, and rises again when begin of setting and C–S–H production (temperature "hydration

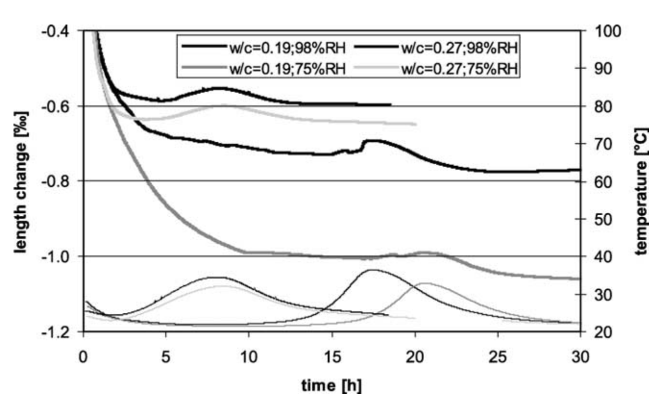

Fig. 4. Length change (▬) and temperature (▬) of pure Portland cement paste at 98% and at 75% relative humidity.

peak''). Interaction between cement and admixture not only affects the fluidity of cement paste, but also causes stiffness like pseudo-setting, or remarkable retardation of setting [17]. The retardation of setting is indicated by a postponed temperature hydration peak. The temperature increases after 3 h for a pure cement paste without superplasticizer and after 15 h with superplasticizer.

A strong initial shrinkage beginning from time zero to 2 h (respectively 5 h with superplasticizer) is measured. Somewhat stronger shrinkage is observed at lower relative humidity, owing to drying. A more moderate shrinkage was observed after that period until the beginning of temperature increase. When the temperature rises (hydration peak), swelling is observed. This expansion is much stronger than the induced thermal expansion. After this, further contraction occurs. The shrinkage is stronger for the paste with the lower w/c-ratio.

The binder system 80 wt.% Portland cement blended with 20 wt.% ultrafine cement is studied in Fig. 5. For all mixes a superplasticizer (2 wt.% of binder) was used. Some significant differences to the behavior of pure Portland cement pastes can be observed. First, total shrinkage is much reduced compared to pastes consisting of pure Portland cement. Second, after the first strong shrinkage, an early swelling starts during the dormant phase (3 h to 15 h after placing) without any temperature change. The peak height is mostly influenced by the surrounding relative humidity. A lower relative humidity leads to a more pronounced peak. The water/binder ratio (binder = ultrafine cement+Portland cement) seems to have a minor influence on the peak height. This swelling peak even leads to the unexpected result, that total shrinkage for the drier climate is less than for the wet climate, especially for the very low w/b (0.16) paste. When the temperature rising starts after 17–20 h, a second swelling peak (length change hydration peak) is observed. The influence of w/c-ratio and surrounding relative humidity on the retardation of

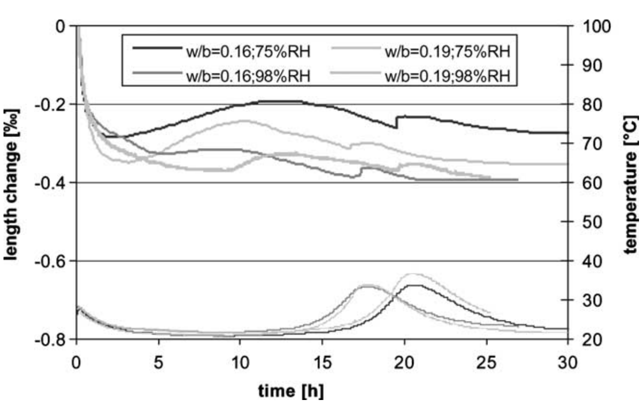

Fig. 5. Length change (▬) and temperature (▬) of a paste of Portland cement (80 wt.%) blended with ultrafine cement (20 wt.%) paste at 98% and at 75% relative humidity.

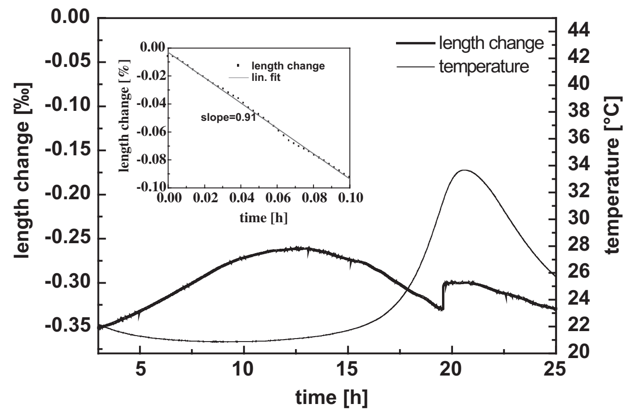

Fig. 6. Detail of shrinkage/swelling of 80% Portland cement and 20% ultrafine cement paste ($w/b = 0.16$).

hydration is not clear. Two concurrent mechanisms may be responsible for retardation. Hydration peak is observed much earlier for even lower relative humidities (after 8 h).

Hence in such dense paste systems five different shrinkage/expansion phases can be distinguished. First phase is a dissolution phase where alkali and sulfate ions are dissolved and first hydration products are formed. An almost linear dependence of length change from time is found (see small plot in Fig. 6). The disjoining pressure [18] caused by capillary forces decreases upon drying. In an intermediate phase shrinkage continues but slows down. First hydration products like ettringite and $Ca(OH)_2$ are formed that might withstand a further shrinkage. Also the decrease of disjoining capillary forces may flatten owing to advanced desiccation. Then a ''desiccation'' swelling follows (Fig. 6). This desiccation peak is this peak is significantly influenced by the surrounding climate. It is stronger for very dense pastes and low relative humidity conditions. It is not found in conventional pastes even with high superplasticizer concentrations (see Fig. 5). The origin of this peak is not clear. A possible explanation could be a change of surface energy owing to increasing ion concentration in the remaining water. Increased drying would rise this ion concentration further and earlier. In fact this peak appears earlier in even drier (35% RH) climate conditions. When temperature rises, mostly through accelerated C–S–H and ettringite formation, another swelling peak is observed. This peak has a very sharp initiation, which could be due to micro-cracking. Finally, further shrinkage, owing to ongoing self-desiccation caused by chemical reaction is observed.

In Fig. 7 is demonstrated that the ''desiccation swelling peak'' is not caused by a chemical process involving the ultrafine cement but originates in the dense particle packing. The ultrafine cement was replaced by inert limestone filler. Despite the good rheological properties, it was not possible to reach such high

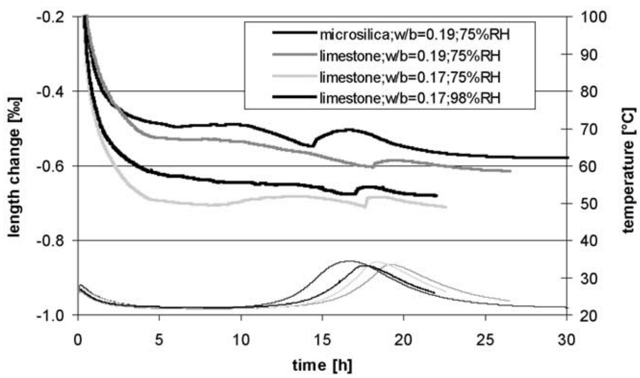

Fig. 7. Length change (▬) and temperature (▬) of Portland cement blended with limestone filler (80:20) and of Portland cement blended with microsilica (90:10) at 98% and at 75% relative humidity.

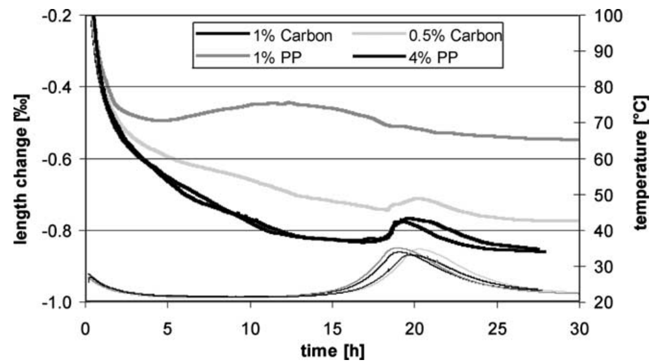

Fig. 8. Influence of the addition of different amount (vol.%) and type of fibers on the length change (▬) and temperature (▬) of cement paste (Portland cement 80%, ultrafine cement 20%, $w/b = 0.19$, 2% superplasticizer) at 75% relative humidity.

packing densities (e.g. similar workability at low w/b-ratios with similar filler content) as with the ultrafine cement. The desiccation swelling peak is observed in dry (75% RH) climate and the lower w/b-ratio (0.17) only. This peak also is observed in a paste consisting of 90% Portland cement and 10% microsilica (see Fig. 7).

Fibers frequently are used to reduce shrinkage. Their effect on early shrinkage is hence studied. Carbon fiber and polypropylene (PP) fiber both with a length of 6 mm was tested. A matrix consisting of 80 wt.% Portland cement and 20% ultrafine cement at a water/binder ratio of 0.19 was chosen. The results are plotted in Fig. 8. A small amount of PP fiber does not affect the appearance of the desiccation swelling peak whereas the "hydration peak" (when the temperature rises) almost disappears. Higher amount of PP fibers or the use of carbon fibers made the "desiccation peak" almost disappear. Early shrinkage was much increased.

2.4. Solid state shrinkage and mechanical properties

After setting further length change occurs depending on the curing conditions. The main processes involved are continued hydration (self-desiccation) and liquid and vapor transport. Water uptake occurs in wet conditions causing expansion, meanwhile drying leads to further shrinkage. As the paste already develops strength after setting, length changes at this stage may introduce severe cracking.

The effect of early age curing conditions on the mechanical properties of hardened cement paste blended with ultrafine cement or limestone filler was studied in a special test series. Mixing was done according EN 196-3 during 3 min. After mixing specimen of $40 \times 40 \times 160$ mm^3 were cast. Mix proportions are given in Table 2. Flexural strength (three point bending, span = 100 mm) and compressive strength (cubes of $40 \times 40 \times 40$ mm^3) were measured at an age of 7, 28 and 90 days. The results are given in Table 3. Very high early strengths are observed, owing to the very low w/c-ratios and the dense structure.

The addition of ultrafine cement increases compressive strength significantly (Table 3). The greatest increase is found for the batch with the biggest amount of ultrafine cement. Curing condition has a minor influence on the compressive strength. Somewhat higher values are found for water curing, especially for high (30%) ultrafine cement content and for early (7d) strength. The

Table 2
Mix proportions of the studied pastes

No.	CEM I 42.5 N (wt.%)	Ultrafine cement (wt.%)	Limestone filler (wt.%)	Superplasticizer (wt.%)[a]	w/b	Slump flow[b] (mm)
1	100	0	0	2.0	0.19	200
2	90	10	0	2.0	0.17	201
3	80	20	0	2.0	0.155	170
4	70	30	0	2.0	0.145	191
5	80	0	20	2.0	0.17	205
6	70	0	30	2.0	0.165	205
7	80	20	0	1.0	0.20	195
8	80	20	0	1.5	0.175	186

[a] Referred to binder.
[b] Without shocking.

Table 3
Flexural and compressive strength

		1	2	3	4	5	6	7	8
Storage water									
R_c[a] (MPa)	7 d	73.7	87.0	105.3	119.8	67.4	73.1	97.7	104.6
	28 d	93.0	101.0	101.7	136.9	88.6	82.8	107.1	118.1
	90 d	101.5	113.8	109.9	127.3	97.8	93.9	112.1	123.1
R_f[b] (MPa)	7 d	15.4	13.1	16.0	2.6	11.5	7.6	18.2	17.6
	28 d	14.9	16.2	19.7	2.3	11.5	9.3	18.1	19.7
	90 d	13.6	13.3	19.4	3.4	12.6	10.6	17.6	18.5
ε (‰) 90 d[c]		+0.91	+0.32	−0.09	+0.68	+0.82	+1.22	−0.08	−0.05
Storage wet									
R_c[a] (MPa)	7 d	70.4	84.7	98.1	105	68.9	65.8	94.1	102.8
	28 d	90.5	103.0	112.0	119.8	91.6	91.4	109.8	111.2
	90 d	101.6	95.0	121.8	122.5	96.3	91.7	108.4	118.5
R_f[b] (MPa)	7 d	13.6	17.0	17.8	18.9	12.4	12.4	20.5	20.8
	28 d	14.6	13.3	13.9	13.1	12.8	15.6	10.9	13.0
	90 d	8.7	11.2	12.8	8.6	15.7	17.3	7.3	8.5
ε (‰) 56 dc		−1.21	−1.01	−0.99	−0.53	−1.10	−1.10	−1.04	−1.08
ε_e (‰)[d]		+0.55	+0.35	+0.22	+0.21	+0.65	+0.64	+0.34	+0.28
ε_s (‰)[e]		−0.66	−0.39	−0.23	−0.21	−0.71	−0.66	−0.40	−0.22

[a] Compressive strength.
[b] Flexural strength.
[c] Length change during hardening.
[d] Expansion under water (56–70th d).
[e] Second shrinkage 70% r.H. (77–90th d).

addition of a limestone filler slightly decreases the compressive strength compared to the pure Portland cement paste. The flexural strengths are significantly influenced by the curing conditions. Curing at 20 °C/95% RH until the 7th day ("wet") increases the flexural strength of hardened cement pastes containing ultrafine cement compared to pure Portland cement significantly. After 7 days these samples were stored at 20 °C/70% RH. That leads to a decrease in flexural strength at the age of 28 and 90 days. At this curing condition the flexural strengths of hardened cement pastes containing ultrafine cement or pure Portland cement decrease with age. In the case of limestone filler however the flexural strength increases.

The addition of ultrafine cement has a positive effect on flexural strength when the samples are stored under water only. For some mixtures a slight decrease of flexural strength with age is observed when water cured. The continuing hydration of non-hydrated cement particles enabled by the diffusion of water may develop internal stress. This may cause cracking [19], leading to a reduction in durability of high strength concrete [20]. Batch 4 with the highest amount of ultrafine cement shows a strong decrease in the flexural strength when stored under water. "Water" storage seems to induce internal stresses. Liquid transport in a such dense matrix is limited, so that inhomogeneous hydration may result. Using microscopy, large cracks with a width up to 10 microns were observed. This effect can be avoided applying an adequate curing. A wet (or steam) curing during the first few days followed by water storage might be ideal for such very dense systems.

A reduction of superplasticizer content (batches 7 and 8 compared with batch 3) leads to a higher water requirement. A positive effect on the flexural strength at an age of 7 days is observed. This might be caused by a retarding behavior of the superplasticizer. The compressive strength for water cured specimen and lower content of superplasticizer (1%, 1.5%) is higher compared to the specimen mixed with 2% superplasticizer.

The length change was measured on distance using small plates fixed after demoulding at an age of 1 day onto the specimens. The results are given in Table 3. Length change depends on the curing conditions. Length change of specimen cured under water is strongly reduced through the addition of a medium amount (10% or 20%) of ultrafine cement. Low length change is coupled with high flexural strength. A strong expansion is observed for hardened cement pastes containing pure Portland cement, limestone filler or high amount of ultrafine cement when stored under water (Fig. 9).

Shrinkage in wet condition is somewhat reduced for hardened cement pastes containing medium amount of

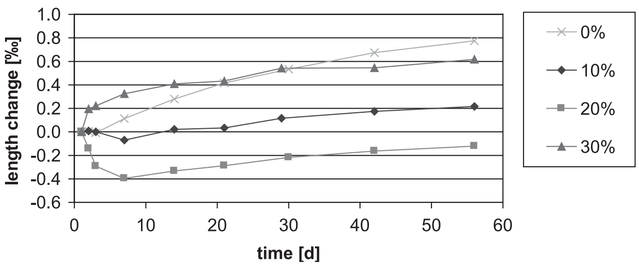

Fig. 9. Influence of ultrafine cement content on shrinkage (water storage).

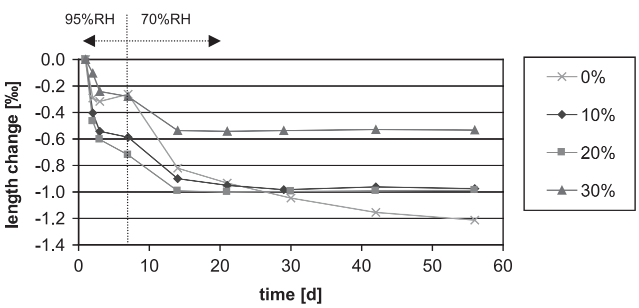

Fig. 10. Influence of ultrafine cement content on shrinkage (wet storage).

ultrafine cement and is significantly reduced by addition of a high (30%) amount of ultrafine cement (Fig. 10). A shrinkage reduction effect was also described by [21]. The addition of limestone filler does not influence length change behavior compared to pure cement paste.

The measurement of the length change (storage of wet specimen under water for 14 days after 56 d and after that storage at 20 °C/70%) shows no reactivation of cement hydration (compare ε_e with ε_s). The specimen containing ultrafine cement show minor length changes upon changes of storage conditions than the other specimen. Samples containing limestone filler however show an important expansion when immersed in water, but this is reversible when they are stored at dry condition again.

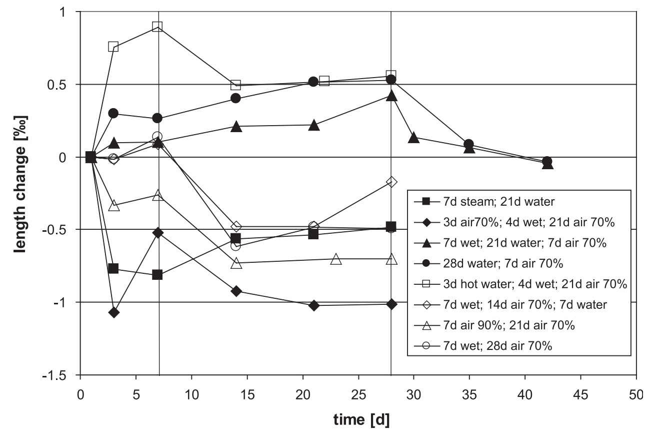

Fig. 11. Length change at different curing conditions of cement paste ($w/b = 0.16$, 80% Portland cement, 20% ultrafine cement).

In a further test series the influence of other curing conditions: steam (50 °C, 95% RH), air 70% (20 °C/70% RH), air 90% (20 °C/90% RH), wet (20 °C, >95%RH), hot water (immersed in water at 90 °C) and water (immersed in water 20 °C) was studied on a paste containing 80% ordinary Portland cement and 20% ultrafine cement ($w/b = 0.16$). The tests were performed on small specimens $15 \times 15 \times 80$ mm^3. The length changes (without temperature correction) are plotted in Fig. 11. The results for the compressive and flexural strengths are given in Table 4. Short wet curing (until 7 days) results in very moderate shrinkage and good mechanical properties of the hardened paste. Even if wet curing is followed by storage in dry conditions (70% RH) high compressive and flexural strength is measured. When these specimens then are immersed in water for 7 days (simulating rain), flexural strength is not affected negatively. On the other hand, long time immersion in water followed by drying, results in a drastically loss of flexural strength. Hot water curing may increase compressive strength but affects flexural strength negatively.

The availability of water during the first days seems to be crucial for the development of the mechanical properties. This should be followed by a dry regime

Table 4
Flexural and compressive strengths of cement paste ($w/b = 0.16$, 80% Portland cement 20% ultrafine cement, 2% superplasticizer)

Storage condition		28d water 7d air 70%	7d wet 21d water 7d air 70%	7d steam 21d water	3d air 70% 4d wet 21d air 70%	7d air 90% 21d air 70%	7d wet 21d air 70%	7d wet 14d air 70% 7d water	3d hot 4d water 21d 70%
R_c[a] (MPa)	7 d	120.3	124.3	–	–	–	–	–	–
	28 d	142.4	151.8	129.5	142.8	125.5	131.8	124.8	155.7
	42 d	144.6	144.3	–	–	–	–	–	–
R_f[b] (MPa)	7 d	18.4	15.9	–	–	–	–	–	
	28 d	16.3	18.4	13.7	15.3	10.9	15.7	16.1	12.4
	42 d	10.4	11.3	–	–	–	–	–	–

[a] Compressive strength.
[b] Flexural strength.

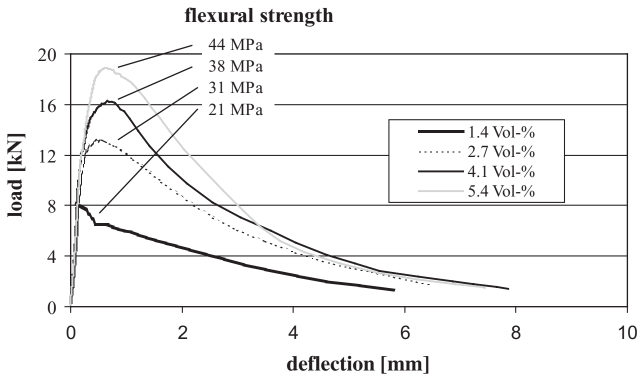

Fig. 12. Load–deflection curve of short (13 mm) metal fiber reinforced cement paste ($w/b = 0.15$, 80% Portland cement, 20% ultrafine cement, 2% superplasticizer).

avoiding damage from swelling or from drying shrinkage at an advanced age.

3. Application

The good rheological properties and the very dense packing of cement blended with ultrafine cement may be used for mixing high performance composites with very good mechanical properties. As an example bending properties of hardened cement pastes containing different amount of metal fiber are shown in Fig. 12. Such materials even fulfil the requirements for a steel bar replacement in concrete. Additionally, the very dense matrix may improve durability of such composites compared to other mixing concepts. Extension of service life, replacement of cost and energy intensive parts as well as weight considerations may make such materials despite the higher material costs a sustainable alternative to actual technology.

4. Conclusions

The effect of the addition of ultrafine cement and different fillers on cement paste rheology and mechanical properties of hardened cement paste was studied.

Rheological properties, especially viscosity and yield value, can be improved by blending normal Portland cement with limestone filler or ultrafine cement. This is caused by the resulting bimodal grain size distribution. Hence the water demand of cement pastes is reduced. Consequently, in combination with superplasticizers, very low w/c-ratio cement pastes can be produced even with conventional mixing and casting techniques. Very dense structures with very low porosity and a high early strength are the result.

Early shrinkage was measured by a new laser system. The influence of different surrounding climate conditions was studied. Early age length change was separated into different phases. Besides shrinkage, two swelling periods were found for very dense low water/binder systems. The first swelling period is related to the degree of desiccation and is hence called desiccation swelling. It is observed during the dormant phase when no temperature rise occurs. The second swelling period is related to the ongoing hydration and is observed together with a temperature rise when setting starts.

The addition of ultrafine cement to normal Portland cement improves the mechanical properties, compressive and flexural strength of hardened cement pastes. While storage conditions during hardening has a minor influence on compressive strength, flexural strength, especially when a high amount (30%) of ultrafine cement is used, can be improved by curing. A wet (>95% RH) curing is preferable to full immersion in water. The addition of limestone filler as a cement replacement is possible without significant loss of strength.

Length change after setting can be widely reduced using medium amount of ultrafine cement and water immersion. In a dry curing condition (7d wet, then 20 °C/70% RH) high amount of ultrafine cement may reduce shrinkage resulting in better mechanical properties.

The blending of normal grain sized Portland cement with ultrafine cement results in materials with exceptional rheological properties. This allows the production of very dense, low w/c materials with good durability and strength properties. Further a modification by introduction of high fiber content is possible leading to materials with high ductility. For the practical application of such dense systems it is of crucial interest to control early age properties. Early age curing conditions influence the properties of such materials significantly. Further practical application may result from the reduced shrinkage at very early age before hydration as well as after setting.

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