CONCRETE WITH ENHANCED DURABILITY

BETON MIT ERHÖHTER DAUERHAFTIGKEIT

PLUS DURABLE BÉTON

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SUMMARY

Durability is mainly a question of transport properties of concrete. Bad curing leads to larger porosity and hence larger diffusivity. By the use of hybrid aggregate concrete bad curing can be avoided even in dry climate. Cracking is the second cause of large permeability. Cracks should be minimized by fibre reinforcement. Since corrosion of steel is one main problem of durability non-ferrous materials would be a remedy.

ZUSAMMENFASSUNG

Die Dauerhaftigkeit von Beton ist hauptsächlich eine Frage der Transporteigenschaften. Schlechte Nachbehandlung führt zu größerer Porosität und daher auch zu größerer Diffusivität. Durch den Gebrauch von hybriden Betonzuschlägen kann schlechte Nachbehandlung sogar in trockenem Klima vermieden werden. Rissbildung ist die zweite Ursache großer Permeabilität. Risse sollten durch Faserbewehrung minimiert werden. Da die Korrosion des Bewehrungsstahls ein wesentliches Problem der Dauerhaftigkeit darstellt, könnten nichtferritische Stoffe (alternative Bewehrung) eine Abhilfe schaffen.

RESUME

La durabilité du béton est une question des propriétés du transport. Un traitement mal cause une grande porosité et diffusivité. Si on utilise des aggregats hybrides on peut améliorer le béton même dans un climat sec. La fissuration est la deuxième cause d´une grande permeabilité. On doit minimiser les fissures avec fibres. Parce que la corrosion d´acier est une problème principal de la durabilité on peut utiliser des armatures non ferreuses.

KEYWORDS: Concrete, durability, cracking, curing, permeability

1. BACKGROUND

Durability of concrete is mainly a question of transport properties and chemical composition. This contribution does not deal with chemical composition and attack due to sulfates or carbonic acid, alkali-silica reaction, and other matters as such, it will not deal with frost action although frost action is also related to transport properties. Most degradation processes depend on the transport properties, one can think about corrosion of reinforcement due to carbonation and chloride ingress but also about the transport of ions which react with the matrix or with the aggregate. Transport properties are a function of porosity and cracking. If one reduces porosity and if one eliminates cracking or keeps the crack width very small durability will increase.

2. CURING

With modern concrete technology one can produce a concrete with low porosity. The means are a low water-cement ratio and use of additions and admixtures together with sound aggregates. But even if the composition is optimal and the compaction is well done something can go wrong by bad curing. Bad curing increases the porosity and hence the permeability. Fig. 1 shows the effect of the degree of hydration on the porosity. Fig. 2 shows the direct effect of curing on the gas permeability of concrete. The difference of blast furnace slag cement vs. portland cement is also visible.

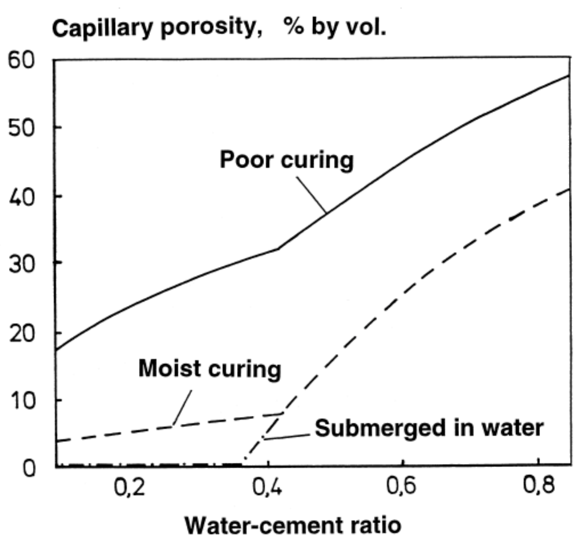

Fig. 1: Porosity of hydrated cement paste as function of water-cement ratio and degree of hydration, acc. to formula in [1]

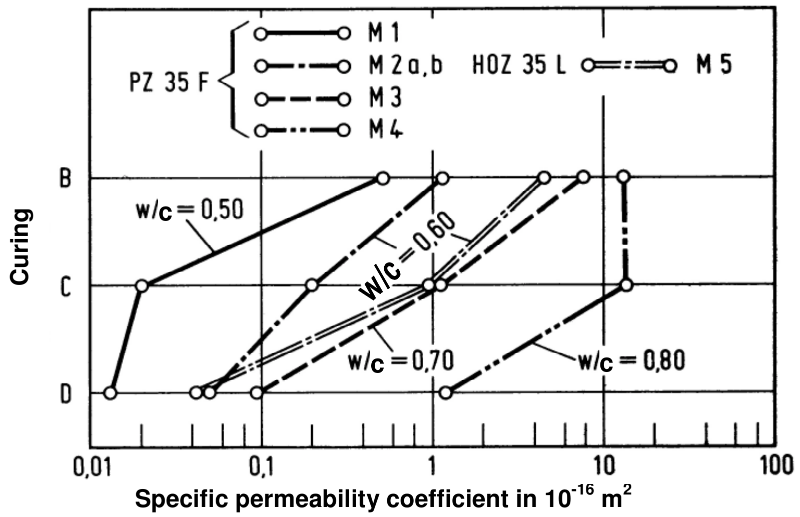

Fig. 2: Effect of curing on gas permeability [2]. Curing: D = 28 d sealed, C = 3 d sealed, B = 1 d sealed, then in air 65% RH, 20°C, age about 50 d, PZ = Portland cement, HOZ = slag cement

3. HYBRID AGGREGATE CONCRETE

Hybrid aggregate concrete (also known as modified density concrete) is a concrete with normal weight aggregates and lightweight aggregates. Light-weight aggregates are either dry or presaturated. They contain water which is used for an internal curing. Experiments have been carried out with various compositions of concrete shown in Tables 1 and 2. Table 1 shows the composition of the matrix. Table 2 contains the various concrete mixes in terms of aggregates used. HB0 is the designation of a normal weight concrete whereas designations HB15 to HB30 belong to the hybrid concrete where the fraction 4/8 mm has been replaced by lightweight aggregate.

Table 1: Paste composition of 1 m^3 fresh concrete [3]

Component	Amount	Unit
Portland cement CEM I 42.5 R	450	kg
Dry mass of silica fume	45	kg
Superplasticizer	13.6	liter
Retarder	1.75	liter
Total water	148.5	liter
Water-binder ratio	0.30	

Table 2: Aggregates of 1 m^3 fresh concrete, unit kg [3]

Aggregates	Type of concrete			
	HB 0	HB 15	HB 25	HB 30
Fraction 0/2 mm	534	522	517	516
Fraction 2/4 mm	281	215	174	174
Fraction 4/8 mm	375	118/262 [1)]	298 [2)]	340 [2)]
Fraction 8/16 mm	558	538	524	449

[1)] 118 kg lightweight, 262 kg normal weight aggregate (in dry state)

[2)] only lightweight aggregate

This type of concrete is mainly interesting for high-performance concrete, i.e. one with a low water-cement ratio. In this case water cannot be transported from outside to the interior of the concrete because of the low permeability of the concrete. Tests have been carried out at very bad curing. As can be seen from Table 3 there has been good curing, normal curing, and very bad curing.

Table 3: Curing regimes after demoulding

Code	Curing regime	Curing efficiency
FK	6 days in fogroom, 20°C, then in air 20°C, 65% RH	good
KK	in air, 15°C < T < 25°C, 40% < RH < 45%	very poor
KL	sealed in aluminium and poly-amid foil	good
KR	in air, 20°C, 65% RH	poor
NK	6 days submersed in water, then in air 20°C, 65% RH	standard, acc. to DIN 1048

The bad curing consisted of no treatment at all at a low humidity of 40%. The next figures show the weight loss distribution in a fictitious column and the strength development at very low relative humidity.

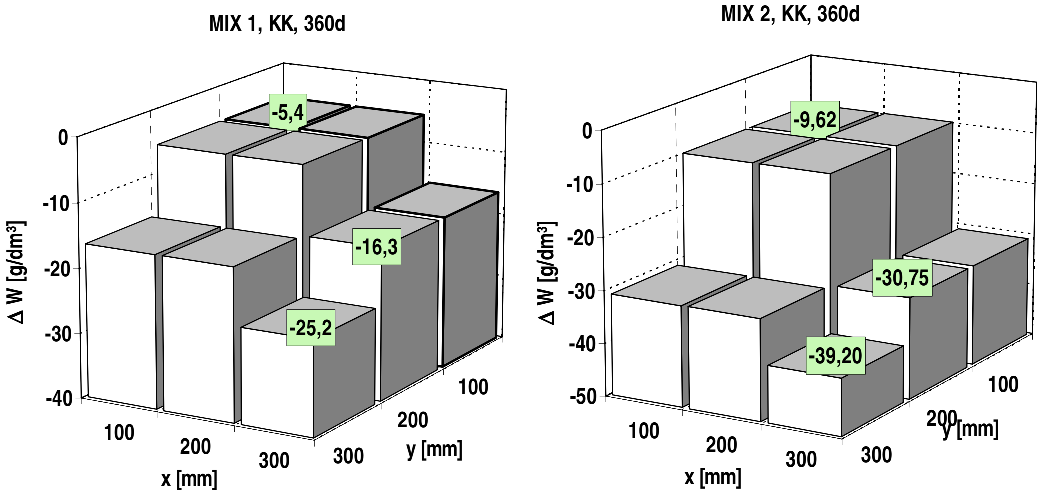

Fig. 3: Distribution of weight loss in the 3 x 3 cubes array after 360 days, a) Mixture 1 (HB0), b) Mixture 2 (HB25) [3]

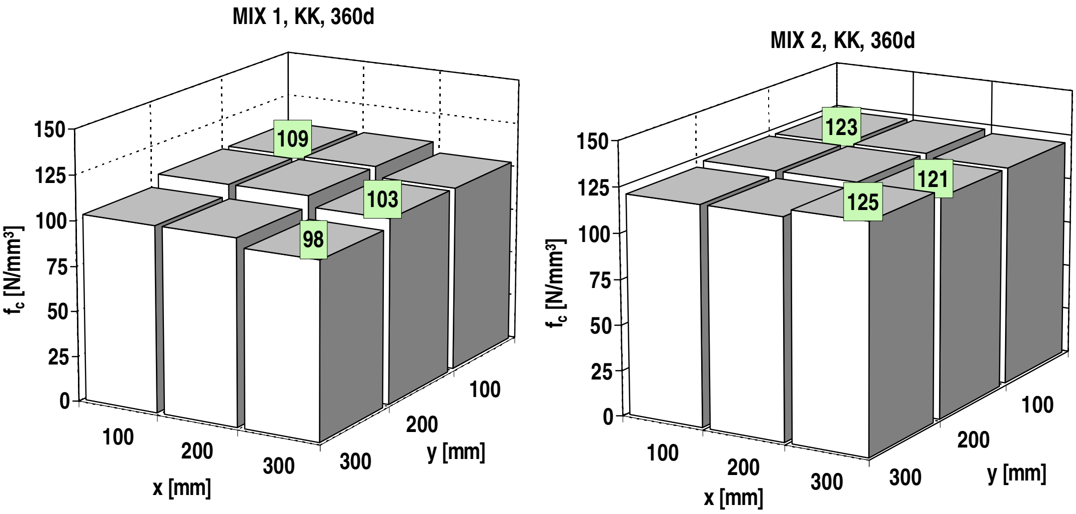

Fig. 4: Distribution of strength in the 3 x 3 cubes array after 360 days, a) Mixture 1 (HB0), b) Mixture 2 (HB25) [3]

It can be seen that the hybrid concrete lost more water than the normal weight concrete. However, due to the storage of extra water in the lightweight aggregates this does not hamper the strength development. The strength of the hybrid concrete is higher than that of the normal-weight concrete.

Shrinkage is substantially influenced by the mix composition as can be seen from Fig. 5. Fig. 5 shows that with larger amount of lightweight concrete shrinkage decreases. Although the final shrinkage has not been reached after a 140 days the shrinkage of concrete with lightweight aggregates has the advantage that the tensile strength develops at the same time and that shrinkage cracks are not likely to occur.

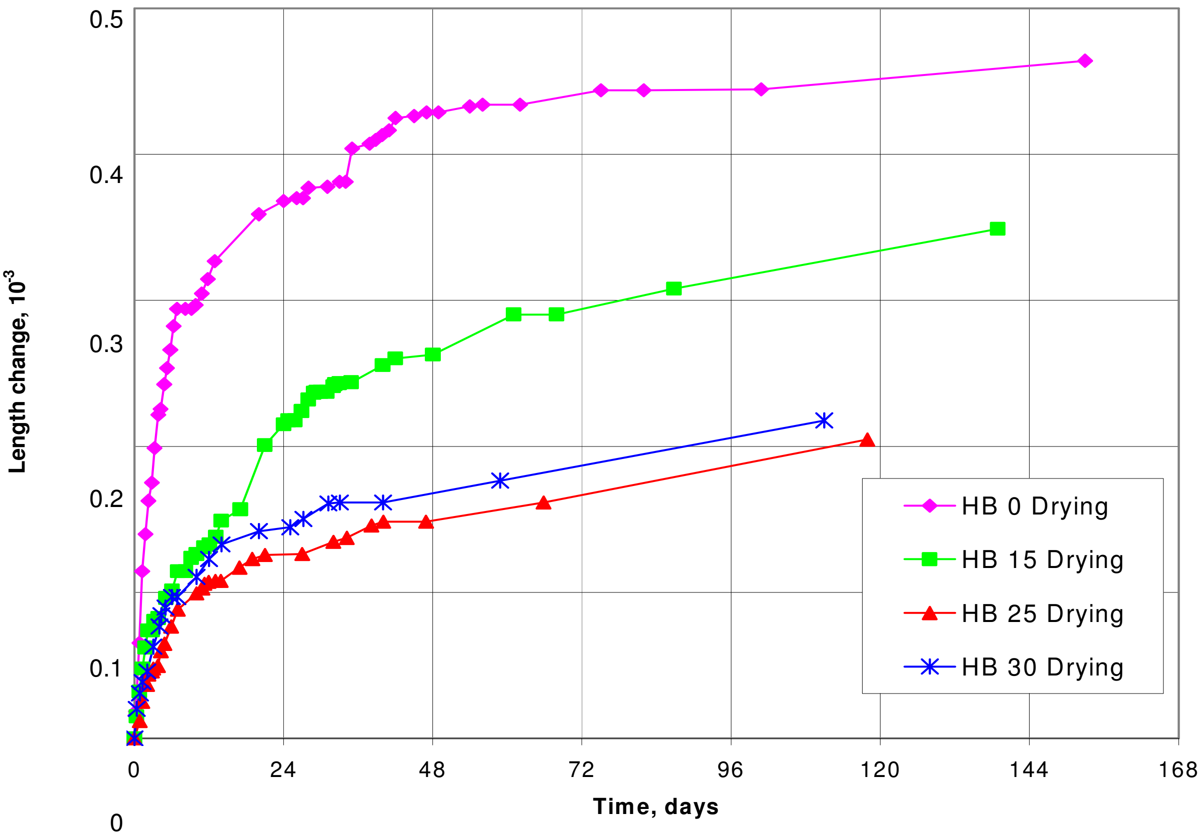

Fig. 5: Shrinkage of drying specimens [4]

The positive influence of lightweight aggregates has also been established by the use of the hydration model of Chaube and Maekawa [5] as is shown by Fig. 6.

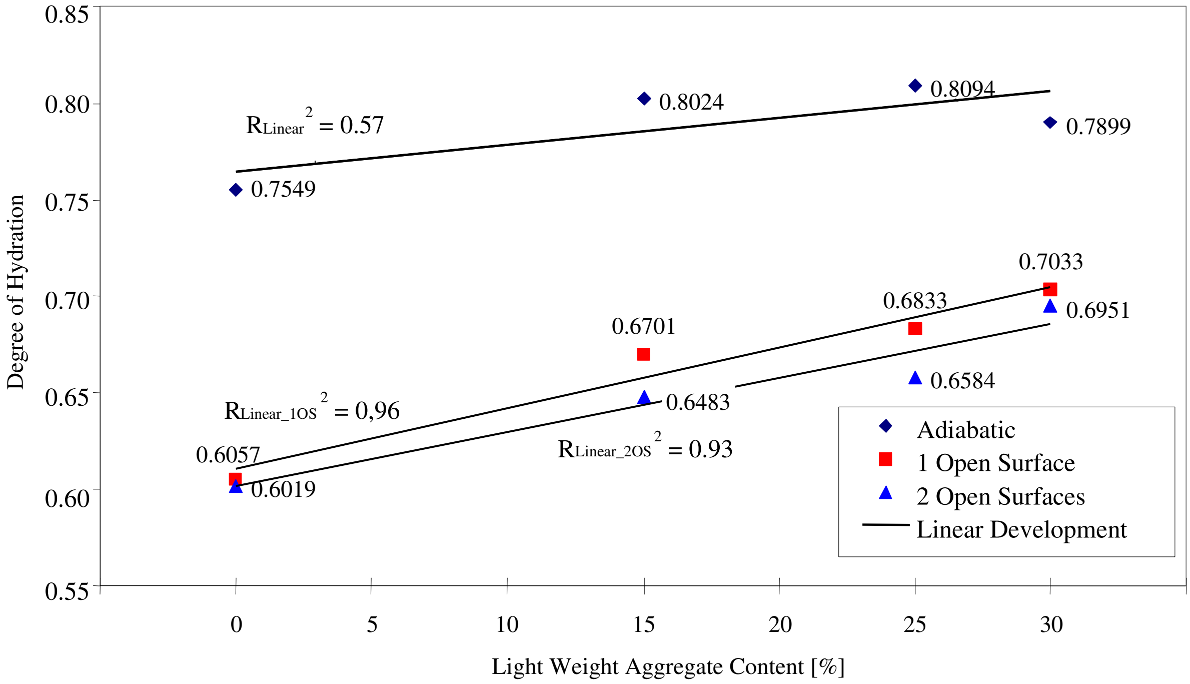

Fig. 6: Degree of hydration at the age of 14 days [6]

The more lightweight aggregate the higher is the degree of hydration at 14 days. The water-cement ratio was 0.33 for all mixes, i.e. the mixing water would not be enough for complete hydration of the cement.

The next generation of hybrid concrete is the one which uses a superabsorbent polymer for the storage of water in the interior which is used for hydration later [7, 8]. Fig. 7 shows two samples of superabsorbent polymer. The left hand picture shows the original dry powder whereas the right hand picture shows the powder mixed with water.

Fig. 7: Superabsorbent polymer, left: dry, right: mixed with water [9]

Fig. 8 gives an impression about water absorption by superabsorbent polymers.

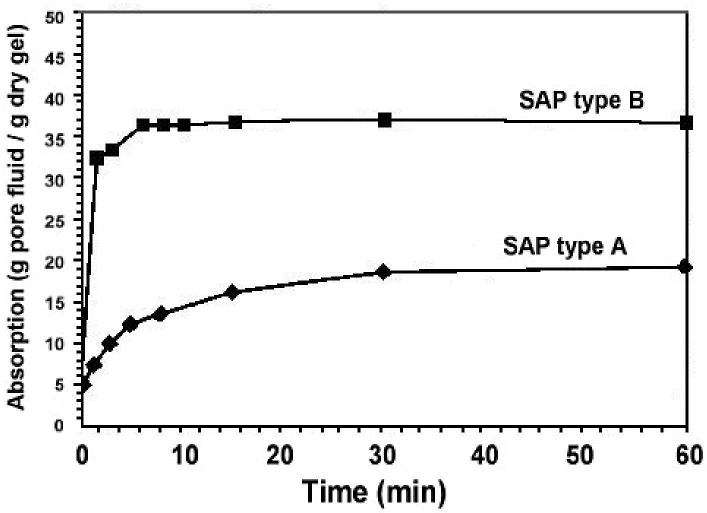

Fig. 8: Water absorption by superabsorbent polymers [7]

It can be seen that various types of superabsorbent polymers exist which are very different in their absorbing capacity. Type B absorbs water very quick within about 2 min. and has an absorption degree of more than 35 g water with respect to 1 g of dry gel. Type A absorbs water less and slower than type B. The maximum water absorption after 30 min. is only 17 g fluid/g dry gel. It should also be mentioned that many superabsorbent polymers cannot be used in concrete because they collapse in an ionic environment.

These were the means how to produce a robust concrete which does not need curing.

4. CRACKS

Another inherent feature of concrete is cracking. Cracking may be due to loading or may be strain induced such as by shrinkage or temperature. The permeability is a function of crack width. Theoretically, the permeability of a crack depends on the third power of the width. Fig. 9 gives an example for water permeability. Another investigation with organic chemicals has shown that a crack with about 0.04 mm width behaves as uncracked concrete. Fig. 10 shows a result.

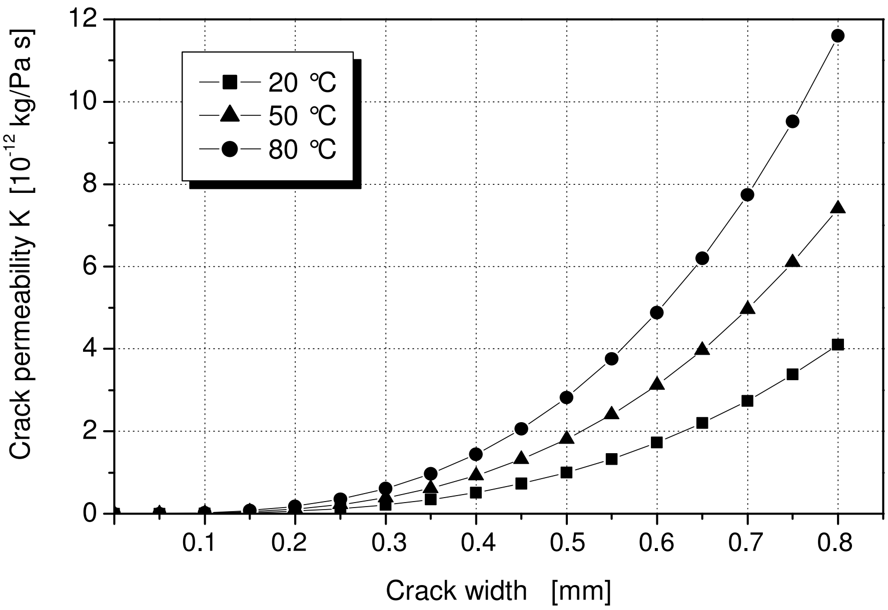

Fig. 9: Crack permeability as function of crack width and temperature [10]

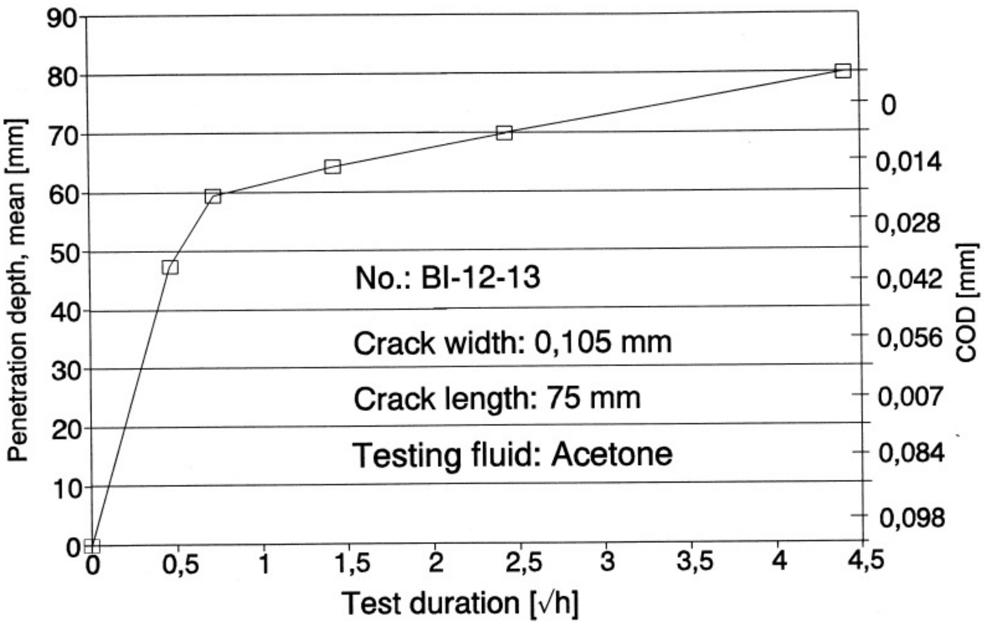

Fig. 10: Penetration of acetone in a crack as function of time [11]

From these observations it follows that a robust, i.e. curing insensitive concrete and a concrete with tiny cracks leads to enhanced durability.

5. ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

In order to make cracks very fine ECC have been developed. ECC consists of a cementitious matrix with a rather high percentage of fibers. About 2% polymer fibers are added which make the matrix rather ductile. The maximum aggregate size of this concrete is 1 to 2 mm. This means that this concrete cannot be used for large structural applications but it can be used for overlays in bridges or for layers in repair work. An example of a composition is given in Table 4.

Table 4: Composition of a typical ECC [12]

Cement	Water	Sand	Fly ash	SP	V_f (%)
1.0	0.53	0.8	1.2	0.03	2.0

The ductility is very large as can be seen in Fig. 11. The material exhibits a strain-hardening behaviour. The tensile strength is about 3.5 MPa but the ultimate strain is more than 5% [12].

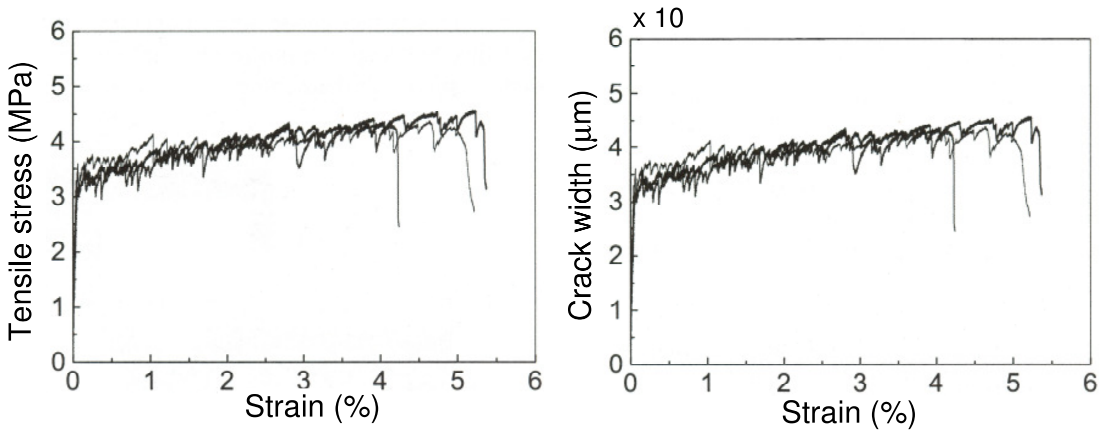

Fig. 11: Tensile stress-strain and crack width curves of ECC [12]

The picture on the right shows that the crack width is in the range of 40 μm.

6. STANDARDIZATION

The European standardization organisation (CEN) has published a new standard for concrete. In this standard, the various types of attacks are listed in a very systematic way. There are two main types of attack, the one is corrosion of reinforcement and the other is degradation of concrete. The list contains XC for carbonation attack, XS for seawater attack and XD for chloride attack by other sources than seawater. The second category contains XF for frost and frost and deicing salts and XA for chemical attack. In Germany, there is an extra category for mechanical abrasion. All these categories have examples of exposure. In an extra table the composition of a concrete is given which fulfills, at a minimum level, the requirement for such an attack.

7. NON-FERROUS REINFORCEMENT

Due to the immense consumption of the Chinese economy the steel prices went up. Therefore non-ferrous reinforcement is now attractive. Furthermore, it has the advantage that it does not corrode. So, the cover to reinforcement can be reduced and the elements get lighter.

8. CONCLUSION

Durability of concrete is mainly a question of transport properties in the bulk material and through-cracks. It has been shown that fluid transport in cracks is a function of the third power of crack width. Therefore concrete structures should be designed and built in such a way that only tiny cracks can occur. A remedy would be the use of engineered cementitious composites which are however only applicable for thin-walled products. To design a robust concrete which does not need curing is hybrid aggregate concrete with incorporation of lightweight aggregates. This concrete shows a smaller shrinkage and thus it is less likely to cracking. A standardisation with clear distinction of exposure classes as developed by the European standardisation organisation can also enhance durability. Finally, the use of non-ferrous reinforcement prevents corrosion and may be advantageous in some applications, mainly with salt exposure.

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