[9] Lepech, Michael, and V.C. Li, "Water Permeability of Cracked Cementitious Composites", *Proceedings of Eleventh International Conference on Fracture*, Turin, Italy. March 20-25, 2005.

[10] Li, V.C., Fischer, G., Kim, Y.Y., Lepech, M., Qian, S., Weimann, M., Wang, S., "Durable Link Slabs for Jointless Bridge Decks Based on Strain-Hardening Cementitious Composites", Report for Michigan Department of Transportation RC-1438, November 2003.

[11] Li, V.C., T. Horikoshi, A. Ogawa, S. Torigoe and T. Saito, "Micromechanics-based Durability Study of Polyvinyl Alcohol-Engineered Cementitious Composite (PVA-ECC)," *ACI Materials J.*, 101(3), pp. 242-248, 2004

[12] Zhang J., Li, V.C., "Monotonic and Fatigue Performance in Bending of Fiber Reinforced Engineered Cementitious Composite in Overlay System ," *J. of Cement and Concrete Res.*, 32(3), pp. 415-423, 2002

[13] Suthiwarapirak, P., T. Matsumoto, and T. Kanda, "Flexural Fatigue Failure Characteristics of an Engineered Cementitious Composite and Polymer Cement Mortars," J. Materials, Conc. Struc. Pavements, JSCE No. 718/V-57, pp. 121-134, November 2002

[14] Thoft-Christensen, P. "Modeling of the Deterioration of Reinforced Concrete Structures" IFIP Conference on "Optimization and Reliability of Structural Systems", Ann Arbor, MI, USA, pp. 15-26 September 25-27, 2000

[15] Li, V.C., and M. Lepech, "Crack Resistant Concrete Material for Transportation Construction," in *TRB 83rd Annual Meeting, Washington, D.C., Compendium of Papers CD ROM*, Paper 04-4680, 2004.

THE INFLUENCE OF SURFACE PREPARATION ON THE BEHAVIOR OF ECC/CONCRETE LAYER REPAIR SYSTEM UNDER DRYING SHRINKAGE CONDITIONS

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Abstract

The paper presents the effect of concrete substrate surface preparation on the performance of Engineered Cementitious Composites (ECC)/concrete layer repair system under restrained drying shrinkage. In repair applications where "new" repair materials are bonded with "old" concrete, drying shrinkage often induces surface cracking in the repair materials, together with interface delamination between the repairs and the concrete substrates. Experimental study shows that when a "smooth" concrete substrate surface was present, the interface delamination was large. However, when an adequate bond was achieved by roughing the surface and/or using bonding agent, the high ductility of ECC could suppress large surface cracks and interface delamination, therefore greatly improving durability and structural integrity of the repair system.

The performance of ECC repair, which is dependent on concrete substrate surface preparation, is significantly different from repairs made of brittle or quasi-brittle materials. Discussions are made on the potential impact on the current ACI Repair Guide with the application of ECC as innovative concrete repair material.

1. INTRODUCTION

1.1 Motivation

A large number of existing concrete structures worldwide, including previously repaired ones, are suffering deterioration or distress. These structures are in urgent need of effective and durable repairs, which should address underlying concrete deterioration problems and protect underlying concrete from aggressive environment in the long term.

Concrete repair is a complex process, and current experiences with concrete repair are not satisfying. It has been estimated that almost half of all concrete repairs fail in field [1]. They are often perceived to lack both early age performance and long-term

durability due to the inherent brittleness and susceptibility to fracture of the repair material, or lack of compatibility between repair material and the surrounding concrete. Many undesirable repair behaviors can be observed in the field in the forms of early age surface cracking or interface delamination between the repair and the concrete substrate due to restrained drying shrinkage. Cracking and delamination are the insidious causes of many repair pathologies. They facilitate the ingress of chlorides, oxygen, moisture, alkali or sulphates into the repaired system and accelerate further deterioration. For example, water penetrating through cracks can contribute to corrosion of reinforcement or freezing-and-thawing damage. Furthermore, the loss of structural integrity impairs load transfer between the repair and the concrete substrate. As a result, the repaired structure with unsatisfactory performance and unexpectedly short life must be repaired again, leading to significantly increased service life cost, which sometimes can be several times greater than the initial cost of structural design and construction.

For users to make successful repairs with maximum life, the ACI Concrete Repair Guide ACI 546R-04 [2] provides guidance on repair material selection, concrete substrate surface preparation and bonding methods. It also refers to ACI Concrete Building Code ACI 318-02 [3] which recommends using shrinkage and temperature reinforcement to control cracking. These ACI recommendations or stipulations may need to be reconsidered in light of the unique properties of high performance fiber reinforced cementitious composites (HPFRCC).

The approach of this research is to utilize Engineered Cementitious Composites (ECC), a new class of HPFRCC, as the repair material to make durable concrete structure repairs. Experiments were carried out on simulated layer repair systems under controlled humidity, with variables of repair material type and surface preparation. Measurements of surface cracking and interface delamination magnitude and extent confirm the effectiveness of simultaneously suppressing shrinkage induced repair surface cracking and interface through the use of ECC as the repair material. Influence of concrete substrate surface preparation on the performance of layer repair systems based on different types of repair materials is also evaluated. The experimental results will also serve as a basis for discussion of potential differences in concrete repair design between using ECC repair material and using traditional repair materials.

1.2 Background

In concrete repair applications, the immediate shrinkage deformation of the "new" repair material after placement is restrained by the "old" concrete substrate which has already undergone shrinkage. Consequently, tensile stress is built up in the repair layer, and shear stress are developed along the interface between the repair and the concrete substrate. These stresses may result in surface cracking of the repair layer, and/or interface delamination.

Li [4] illustrated the effect of inelastic strain capacity of cementitious material on the deformation behavior of a 2-D slab geometry restrained at its ends. For brittle or quasi-brittle repair material with tension softening behavior, the cracking potential under restrained shrinkage is defined as:

$$p = (\varepsilon_{sh} - (\varepsilon_e + \varepsilon_{cp})) \quad (1)$$

where ε_{sh} is shrinkage strain, ε_e is elastic tensile strain capacity, and ε_{cp} is tensile creep strain. If $p \geq 0$, one single crack forms in the repair material, with crack width proportional to the cracking potential p and increasing with the brittleness of the material.

In the case of a repair layer, the boundary conditions are different from the above. Restraint is applied at the base of the slab rather than at its ends, leading to a number of distributed cracks along the repair layer. In ACI 546R-04 [2], most of repair materials referenced are brittle materials, such as conventional concrete and mortar. In these materials, traction-free cracks will open with a crack width proportional to p. By this means, stresses built-up can be relaxed, resulting in little or no shear at the repair/substrate interface. Therefore, delamination at the interface is expected to be small.

Fiber Reinforced Concrete (FRC) is also included as a type of repair material in Section 3.2.6 of ACI 546R-04 [2]. Fibers are added to achieve greater resistance to drying shrinkage and service-related cracking. For common tension-softening FRC material, shrinkage induced stresses are expected to induce surface cracking similar to normal concrete. However, since the cracks are bridged by fibers, the width may be expected to be smaller, and some amount of tensile stress is maintained in the layer. As a result, the interface shear stress is not relieved, so that delamination may be more prominent than normal concrete.

In order to suppress both surface cracking of the repair layer and interface delamination, the repair material will need to exhibit "plastic straining" in order to relieve the tensile stress built up by restrained drying shrinkage. Once plastic straining occurs, the interfacial shear stress will also be relaxed, and interface delamination may be minimized. Plasticity in the form of microcrack damage has been demonstrated in high performance fiber reinforced cementitious composites (HPFRCC). These materials exhibit an ultimate strength higher than the first crack strength, and accompanied by a large strain capacity ε_i at ultimate strength. For such materials, the cracking potential [4] is modified as

$$p = (\varepsilon_{sh} - (\varepsilon_e + \varepsilon_i + \varepsilon_{cp})) \quad (2)$$

Engineered Cementitious Composites (ECC) [5] represents a class of HPRFCC which has been optimized to have large values of ε_i at minimum fiber content. This is accomplished by engineering the microstructure of the composite so that the fiber, matrix and their interface interact mechanically in such a way as to suppress the common form of localized fracture due to Griffith crack propagation, in favor of flat steady state micro-cracking. The micromechanics theory behind the conditions for multiple cracking has been used to tailor the three phases of the composite systematically [6]. Figure 1 shows a typical uniaxial tensile stress strain curve of ECC with a strain capacity of 5%, about 500 times of that of normal concrete [7]. This high ductility of ECC is achieved by formation of many closely spaced microcracks. These microcracks are not "real cracks" since they keep carrying increasing load after formation, therefore allowing ECC

to exhibit strain hardening behavior similar to ductile metals. For this reason, the microcracking in ECC may be referred to as "damage", distinguishing it from real cracks which open with decreasing traction, or localized fracture. Figure 1 also shows the development of crack width with increasing straining. After a strain of about 1%, the early cracks stopped widening and maintain more or less constant crack width less than 60μm. This steady state crack width can be tailored to have different values. Further deformation will be accommodated by additional microcracks till the material was saturated with these microcracks. The strain-hardening ECC has low permeability similar to uncracked concrete [8]. The cracking potential p of this ECC material is highly negative, indicating that localized fracture due to restrained shrinkage will never occur [4]. The high tensile ductility of ECC material, together with its tight crack width during strain hardening, suggests that ECC can be a promising material for durable repair jobs.

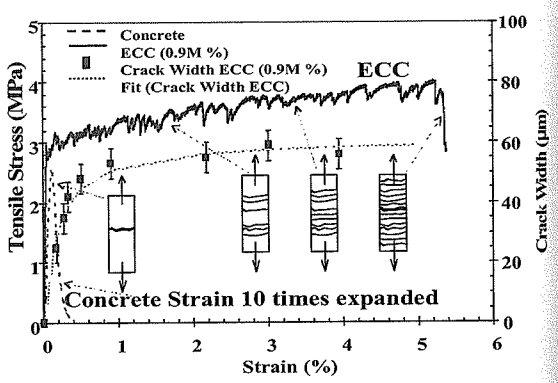

Figure 1: ECC typical tensile stress-strain curve and crack width development

2. EXPERIMENTAL PROGRAM

2.1 Materials

Three different repair materials, concrete, a tension softening steel fiber reinforced concrete (SFRC) and ECC were used in this study (Table 1). Concrete and SFRC were employed as controls since they have been used in repair applications and included in ACI 546R-04 [2].

Table 1: Repair materials composition and properties

Material	C	W	S	FA	CA	SP	V_f	μ_u %	f_c' (MPa)	E (GPa)	Comment
Concrete	1.0	0.4	1.3	--	1.3	0.01	--	0.01	60±1	26±1	brittle
SFRC	1.0	0.4	1.3	--	1.3	0.01	0.01	0.01	63±2	26±1	quasi-brittle
ECC	1.0	0.53	0.8	1.2	0	0.03	0.02	3~5	62±2	20±1	ductile

Both concrete repair and concrete substrate in this study had the same material composition (Table 1). SFRC mixture contained 1% (V_f, volume fraction) steel fibers, with length of 30mm and diameter of 500μm, and smooth surface and hooked ends.

The ECC mixture is comprised of Type I Portland cement (C), water (W), silica sand (S) with 0.1mm nominal grain size, type F fly ash (FA), and 2% (V_f) poly-vinyl-alcohol

(PVA) fibers. These PVA fibers (PVA-REC 15) had length and diameter of 12mm and 39μm. The ECC has compressive strength of 62±2 MPa. Its Young's modulus was lower (20±1 GPa) than concrete and SFRC due to the absence of coarse aggregate (CA) in its composition. A lower modulus repair material is desirable to aid in the relaxation of tensile stresses induced by drying shrinkage according to ACI 546R-04 [2]. The ECC has tensile strain capacity of more than 3% from age of 24 hours to 200 days.

2.2 Specimen Configuration and Surface Preparation

Layer repair systems were experimentally investigated with each of the three repair materials – concrete, SFRC and ECC. Concrete substrates were cast initially with dimensions of 1560mm×100mm×100mm, as shown in Figure 2. The concrete substrates were moisture cured until the age of 28 days, and then left to dry in ambient condition for an additional 60 days before the repair layers were placed. The additional 60 days were for the purpose of allowing any potential shrinkage in the substrates to occur before bonding the repairs. The contact surfaces of the concrete substrates were prepared in four different ways: (a) normally cast (smooth); (b) roughened to 4~5mm; (c) roughened to 7~8mm; and (d) roughened to 7~8mm + cement bonding slurry. For (b), (c) and (d), the substrate surfaces were roughened in fresh state using a chisel to remove slurry cement from external surfaces of coarse aggregates. Before placing the repair layers, the substrate surfaces were recleaned with a brush and high-pressure air to ensure a clean bonding surface, and then they were damped to an adequate moisture level. After this, 5-cm-thick repair layers were cast on the top of the concrete substrates, using each of the three repair materials. If cement bonding slurry was used, a thin coating of "creamy" grout was vigorously and thoroughly brushed into the prepared surface immediately before placing the repair material.

The repair layers were moisture cured for 24 hours and then demolded. After demolding, the layer specimens were moved into a room which has ambient conditions of 20-30℃, and 25-55% RH. For each specimen, two dial gauges were used to record interface vertical separation distance at end locations of the specimens as a function of drying time after delamination begins. In addition, a portable microscope was used to measure the delamination data at 20 different locations along the interface, from which the delamination crack profile was derived. The microscope was also employed to observe crack pattern, crack number and crack width of the top surface of the repair layer, as a function of age. Both the delamination and the surface cracking were measured on a daily basis.

Free shrinkage tests were also carried out to characterize free shrinkage properties of concrete,

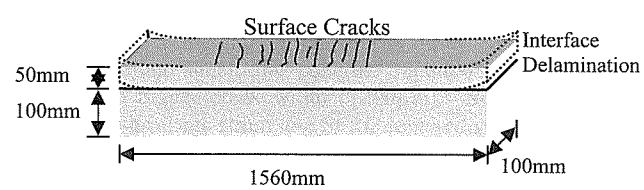

Figure 2: Layer repair system configuration and potential failure modes

SFRC and ECC mixtures. The free shrinkage tests specimens were from the same batch as the repair layer mix for each of the three repair materials. The tests were conducted according to ASTM C157/C157-99 and ASTM C596-01 [9] standards, except that the storing and testing environments of the specimens were modified to be exactly the same as the layered specimens, with ambient condition of 20-30℃ and 25-55% RH. It is for the purpose of relating the free shrinkage tests results to behavior of the layered specimens.

3. EXPERIMENTAL RESULTS

3.1 Shrinkage of Repair Materials

Three specimens were tested for each material and the average free shrinkage strain (ε_{sh}) values were summarized in Table 2. The cracking potential p for concrete, SFRC, and ECC can be estimated, based on measured values of ε_{sh} and ε_i, and other parametric values (ε_e and ε_{cp}) from [4]. Although ECC had the highest shrinkage strain due to higher cement content and absence of coarse aggregates, the p-values for the three materials confirm that concrete and SFRC are subjected to tensile fracturing due to restrained drying shrinkage, while ECC will experience microcrack damage in the inelastic straining range.

Table 2: Concrete, SFRC and ECC cracking potential estimation

Properties	μ_{sh} (%)	μ_e (%)	μ_i (%)	μ_{cp} (%)	$p = \mu_{sh} - (\mu_e + \mu_i + \mu_{cp})$ (%)
Concrete	0.07	0.01	0	0.02 ~ 0.06	0 ~ 0.04
SFRC	0.053	0.01	0	0.02 ~ 0.06	(-0.017) ~ 0.023
ECC	0.177	0.015	3 ~ 5	0.07	(-4.908) ~ (-2.908)

3.2 Cracking of Repairs and Interface Delamination

The experimental results show that with a normally cast (smooth) substrate surface, concrete, SFRC and ECC repair all exhibited relatively large delamination heights and lengths (Table 3). It should be noted that the delamination values (height and length) of ECC repair were significantly higher than the other two repair materials, very probably due to the large fly ash content in its mix and its relative low chemical bond with the concrete substrate.

Table 3: Interface delamination and surface cracking of different layer repair systems

Repair Material	Surface Preparation	Delamination		Cracking	
		Height (μm)	Length (mm)	Number	Width (μm)
Concrete	Smooth	410	320	2	120-130
	4-5mm roughened	190	172	3	130-190
	7-8mm roughened	65	50	4	220-270
	7-8 mm roughened + bonding slurry	32	23	4	210-360
SFRC	Smooth	550	397	2	90-120
	4-5mm roughened	370	375	5	70-110
	7-8mm roughened	275	350	3	120-140
	7-8 mm roughened + bonding slurry	310	354	4	90-150
ECC	Smooth	1225	722	0	--
	4-5mm roughened	425	402	21	10-60
	7-8mm roughened	53	50	76	10-60
	7-8mm roughened + bonding slurry	40	31	103	10-60

For concrete repair, enhancing interface bonding by roughening methods and/or adding bonding agent (cement-based slurry) did reduce the delamination values. However, the crack pattern and width did not change a lot. Concrete repair always exhibited several localized cracks with large crack width (>100μm), which was determined by concrete material cracking potential p. Furthermore, stronger interface bonding actually led to larger surface cracking width, since more shrinkage deformation had to be released by opening cracks.

For SFRC repair, no significant changes in interface delamination values were observed. Even with a deeply roughened substrate surface and application of bonding agent, the delamination height and length were still big, due to the high cracking potential p of SFRC and bridged cracks which could not open freely.

For ECC repair, with enhanced interface bonding, the delamination height and length was significantly reduced, and the multiple cracking phenomenon became more and more predominant. For the "roughened to 7-8mm" and "roughened to 7-8mm + cement bonding slurry" cases, under environment with the same relative humidity and temperature, the ECC repaired system exhibited the most desirable performance. The crack width of the ECC repair and the interface delamination were both very small (<60μm), which was ideal for achieving durability. Conversely with the deeply roughened interface and bonding agent, the concrete repaired system had several localized fractures with much bigger crack width (>200μm). Surprisingly, although SFRC repair had the smallest shrinkage strain, the SFRC repaired system exhibited both large crack width (120-140μm) and large interface delamination height (>275μm) and length (>350mm), severe enough for introducing undesirable agents into the repaired system, resulting in a lost of durability. The experimentally revealed effects of interface bond strength on the repair layer surface cracking and interface delamination behavior are consistent with those numerically predicted by Kabele (2001) [10].

4. IMPLICATIONS FOR REPAIR APPLICATIONS

This study verified the outstanding performance of ECC repaired system under restrained drying shrinkage conditions, suggesting ECC as a promising material to make durable concrete structure repairs. When an adequate bond was provided, ECC repair developed multiple microcracks rather than several localized cracks, consequently suppressed interface delamination under restrained drying shrinkage. Unlike other brittle or quasi brittle materials, the tight crack width of ECC is a material property, which is independent of structural dimensions. This implies that with increasing structural scale, the advantage of using ECC as the repair material will be even more important.

Surface preparation is one of those basic conditions provided by ACI 546R-04 [2], which should be met before repair material placement. Section 2.7 within ACI 546R-04 [2] recommends using in-place tensile pull-off tests to evaluate whether the surface preparation and the bonding of repair materials are adequate. Failure in substrate is preferred, which means that materials having high bonding strength with the old concrete are more likely able to make repairs with sound performance and durability. Experimental results from this study show that sufficient bonding strength is necessary for ECC repair material to perform well. However, for brittle or quasi brittle repair materials with high cracking potential, enhancing interface bonding strength should have very limited aid in achieving durability of the repaired structure. Once sufficient stresses have been built up in the repaired system due to restrained repair volume change, stronger bond does reduce the trend of interface delamination, but promotes the tendency of surface cracking and potentially increases cracking number or width. Therefore, special attention needs to be paid to the intent of the pull-off test because it over-simplifies the interaction between the repair and the concrete substrate, and neglects the delicate competition between the formation of cracks and delamination. Simply seeking strong bond while ignoring repair material tensile ductility cannot ensure durable repairs.

In Section 3.7 of ACI 546R-04 [2], repair material with minimal shrinkage is recommended for interface integrity. Ultimate drying shrinkage of cement-based repair material is limited to below 0.1%. However, experimental results from this study reflects that cracking potential p is much more related to repair behavior under restrained drying shrinkage rather than the free drying shrinkage value. Even with ε_{sh} less than 0.1% (0.07% for concrete and 0.053% for SFRC), repairs made of concrete or SFRC all exhibited cracking or interface delamination to various degrees. This is because of their low strain capacity (~0.01%) and consequent large value of cracking potential. In contrast, although ECC has ε_{sh} more than 0.1% (0.177% in this case), with a negative cracking potential p=(-4.908)~(-2.408), it suppressed localized fracture. Simultaneously, the large tensile ductility of this material relaxes any potential stress build-up in the repair layer, thus minimizing the delamination of the interface. Tensile deformation of the repair layer was accomplished by multiple microcrack damage. The experimental results validate the concept that ductility of repair material is essential for achieving durability of repaired structures.

In addition, ACI 546R-04 [2] refers to ACI 318-02 [3], which recommends using shrinkage and temperature reinforcement to control cracking in Section 7.12 [3]. A minimum reinforcement ratio of 0.0014 ~ 0.002 is specified depending on steel grade. The shrinkage and temperature reinforcement is required to be spaced not farther apart than 5 times the slab thickness, nor farther apart than 18 in. By virtue of the tight crack width control of ECC at strain hardening stage, which is normally below 60μm, these cracking control reinforcement may not be needed at all. Furthermore, the potential elimination of cracking control reinforcement also greatly reduces the risks of steel corrosion and cover spalling, which are very common repair pathologies in the field. It also makes the repair jobs simpler. Consequently, both construction cost and maintenance cost can be greatly reduced.

5. CONCLUSION

A material based methodology, by using ductile ECC material, is proposed and experimentally validated in this study for improving durability of repaired concrete structures. Repair material ductility is closely related to cracking potential under restrained volume change such as drying shrinkage or thermal effect. In this sense, repair material ductility should be given great importance in future concrete repair design guides. When repair material ductility requirement is satisfied, crack control reinforcement and material free drying shrinkage limit become less important, while surface preparation methods to enhance interface bond will be more meaningful on achieving durability of repaired concrete structures.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Mather, B., and Warner, J., (2003). "Why do Concrete Repairs Fail," Interview held at Univ. of Wisconsin, Dept.of Engrg. Professional Development, MD, WI, <http://aec.engr.wisc.edu/resources/rsrc07.html>. Accessed, Nov., 2003.

[2] American Concrete Institute, *Concrete Repair Guide (ACI 546R-04)*, American Concrete Institute. Farmington Hills, MI. 2004

[3] American Concrete Institute, *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)*, American Concrete Institute. Farmington Hills, MI. 2002

[4] Li, V. C., "High Performance Fiber Reinforced Cementitious Composites as Durable Material for Concrete Structure Repair," *Int'l J. for Restoration of Buildings and Monuments*, Vol. 10, No 2, pp 163–180, 2004

[5] Li, V. C., "From Micromechanics to Structural Engineering--the Design of Cementitious Composites for Civil Engineering Applications", *JSCE J. of Struc. mechanics and Earthquake Engineering*, Vol. 10, No.2, pp 37-48, 1993

[6] Li, V.C., "On Engineered Cementitious Composites (ECC) – A Review of the Material and its Applications," *J. Advanced Concrete Technology*, Vol. 1, No. 3, pp.215-230, 2003
[7] Weimann, M. B. and Li, V. C., "Hygral Behavior of Engineered Cementitious Composites (ECC)", *International Journal for Restoration of Buildings and Monuments*, Vol. 9, No 5, pp 513-534, 2003
[8] Wang, K., Jansen, D. C. and Shah, S. P., "Permeability Study of Cracked Concrete", *Cement and Concrete Research*, **27**, 3, pp. 381-393, 1997
[9] American Society for Testing and Materials (U.S. Code Organization)
[10] Kabele, P., "Assessment of Structural Performance of Engineered Cementitious Composites by Computer Simulation", CTU Report 4, V.5, Czech Technical University, Prague, 2001

RAPID HARDENING PVA FIBRE REINFORCED CONCRETE

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Abstract

Repair and replacement of concrete runways have often to be carried out in a few hours in order to minimise disturbance of air traffic. Additionally, requirements regarding durability, warping and crack formation are very stringent. The development of a suitable high performance concrete for this application is a demanding task.

In this contribution, properties of a rapid hardening concrete with high strength, low shrinkage, low thermal gradients during hydration and high frost resistance will be described in detail. In order to reach the required ductility and to ascertain the required structural properties, PVA fibres have been added to the mix. The application of this specially developed advanced high performance concrete for repair of runways at Zurich airport is presented as a case study.

1. INTRODUCTION

Highways, airport runways and similar pavements are exposed to intensive loads. Static and dynamic loads as well as humidity and temperature changes act simultaneously and generate stresses and eigenstresses within the concrete. Particular combinations of different loads often lead to premature crack formation caused by hygral and thermal gradients. Subsquent mechanical loads facilitate the further progression of these cracks. In case of airport runways and parking aereas, such cracks appear within 5 years after construction. Due to safety reasons, strongly damaged concrete slabs have to be substituted. This must be executed within a short time frame during the night in order to minimise the obstruction of traffic. To assure an early return to operation the new material has to meet a wide range of rheological, physical and mechanical requirements.

The repair and maintenance of runways is of particular interest for airport authorities, as these measures do not only generate high costs, but also obstruct the viability, as