Effect of repair materials on durability indexes of concrete

P. Parbhoo, H. Lyimo and S.O. Ekolu,
School of Civil and Environmental Engineering, University of the Witwatersrand, Johannesburg, South Africa

ABSTRACT: In this paper, durability index test methods were employed to assess the influence of repair materials on the durability of concrete. Five (5) commercially available repair materials were studied viz:- two special coatings of masonry and carbothane aliphatic paints, and three repair mortars consisting of general purpose, cement-based, and epoxy resin. The oxygen permeability and the water sorptivity test methods were used to determine and compare the performances of the various repair materials. In addition, three types of substrate surface preparation methods were investigated namely chiseling, cutting and brushing of the substrate. The results of the tests show that repair materials do have significant effect on increasing the durability of concrete. It was found that substrate preparation is an important factor in making a durable repair with wire brushed surface preparation giving best performance and chiseling giving least improvement in results. The epoxy resin repair material uniquely showed water-repellant properties in the sorptivity test, not typical of common concrete material behaviour. Accordingly, the applicability of the index test methods on testing of repaired concrete surfaces in the field may require prior knowledge of the characteristics of the repair material used in order to aid interpretation of their durability index test results

1 INTRODUCTION

Much research has been conducted in the field of concrete durability and a vast amount of repair materials have been developed to improve the durability performance of concrete. These repair materials are highly specialised and are generally highly priced. Although a variety of tests (strength, chemical and electrochemical) are usually conducted on the materials before they are put into production, the long term durability properties of these materials are not well established, in most cases. This investigation work therefore set out to determine the effect that repair materials have on the long term durability of concrete structures.

It should be noted that the repair materials considered in this investigation are not strength enhancers but are designed to protect the reinforcing steel from chemical attack when the surface of concrete has been compromised. Protection of the steel is crucial as reinforcement contributes largely to the load carrying capacity of reinforced concrete and if weakened could cause failure of the concrete structure. Furthermore, different surface conditions were applied onto the concrete by mechanical methods so as to simulate the range of surface preparations that may be carried out before repair materials are applied in practice.

2 LITERATURE REVIEW

In a study conducted by Al-Zahrani, 2003 to evaluate nine polymer- and cement-based repair mortars, the mechanical properties of elastic modulus, compressive, tensile and flexural strength; shrinkage and thermal expansion were tested along with durability properties of chloride permeability, electrical resistivity and carbonation depth. They reported that the mechanical properties of the selected repair mortars did not vary significantly from each other although the elastic modulus of the polymer-based repair mortars was generally less than that of the cement-based repair mortars. There was less drying shrinkage cracking in the polymer-based materials but their electrical resistivity results were higher than those of cement-based repair mortars. Also, enhanced carbonation was noted in some of the polymer-based repair mortars. Both the polymer-based and cement-based repair mortars gave low chloride permeability results.

Almusallam, 2003 reports of a study conducted to evaluate the durability of concrete coated with five generic types consisting of acrylic, polymer emulsion, epoxy resin, polyurethane, and chlorinated rubber coatings. The durability of the uncoated and coated concrete specimens was evaluated by assessing water absorption, chloride permeability and chloride diffusion. Their chemical resistance was evaluated by immersing the uncoated and coated mortar specimens in a 2.5% sulphuric acid solution. Cylindrical concrete specimens 75 mm in diameter and 50 mm high were cast to evaluate the water absorption, chloride permeability and chloride diffusion. Cement mortar specimens were utilized to evaluate the chemical resistance of the selected coatings. The concrete and mortar specimens were cleaned prior to the application of the coatings. After preparation of the surface, the coatings were applied with a brush as per the manufacturer's instructions. The results indicated that epoxy and polyurethane coatings performed better than acrylic, polymer and chlorinated rubber coatings. However, there was noticeable variation in the performance of the same generic type produced from different manufacturers.

The interface between the repair material and concrete surface may represent a weakness in the concrete and so it is imperative to have strong adhesion. Momayez, 2005 used different test methods to evaluate bond strength between the concrete substrate and repair materials. The methods employed consisted of the pull off test, slant shear test, splitting prism test and the bi-surface shear test. The study found that bond strength increased with addition of silica fume in the mixture, regardless of the test methods. Rough surface preparation leads to higher bond strengths and the influence of surface roughness is more pronounced with the repair materials of low adhesion.

The compatibility of the repair materials with the existing substrate is an important consideration if the repairs are to withstand the stresses induced by influences of volume changes and chemical effects. Morgan, 1996 briefly reviews some of the major requirements for the design and construction of durable repairs. The two basic types of repair materials of interest are the cementitious-based repair materials and the polymer-based repair materials. Different types of repair materials will be required for different repair applications and it is the responsibility of the engineer to determine the physical and chemical exposure conditions which the repair material will experience as well as its compatibility with the existing concrete substrate. The properties of repair and substrate that will require matching in order to achieve compatibility will depend on the type of repair. For structural repairs the Young's modulus of the repair material and substrate should be similar, while the strength of the repair material should be greater than that of the substrate concrete. While there is a difference of opinion as to whether or not, the polymer-based repair materials are better than cement-based repair materials, it is agreed that protecting only the damaged area of concrete may cause corrosion to accelerate in the surrounding parts bordering the repair material, due to an electrochemical difference. In order to reduce electrochemical differences, the repair material should be of similar density, composition and permeability as the concrete substrate. Yet the repair material that is impermeable may cause saturation of concrete substrate as it would be unable to 'breath'. This problem occurs especially in hydraulic structures. Portland cement based repair materials do not perform well under aggressive exposure conditions such as severe chemical environments or where high erosion /abrasion conditions prevail. Also, good repair materials are those that are volumetrically stable i.e. they would not shrink or expand significantly once installed and would have similar elastic and thermal expansion characteristics as the concrete substrate.

In discussing repairs, Wood et al., 1990 points out that the key to the success of a structural repair is to ensure the transfer of load from the repair material into the concrete. Failure of repairs generally occurs at this boundary due to a combination of shrinkage, differential thermal strains and applied load. The boundary strength is limited to the lowest of tensile or shear strengths arising from any of the following: (a) the concrete substrate, (b) the concrete underlying the prepared concrete surface which may be damaged earlier or during the repair process, (c) the surface characteristics of the prepared surface, (d) the interface layer including bond coat, (e) the repair material.

There is very little to be gained from repair materials stiffer and stronger than the basic concrete because the repair materials will not act cohesively with the concrete substrate. The concept of "Repair Like with Like" is introduced. All the normal requirements for long term chemical stability and chemical compatibility of ingredients must be considered for repair materials. Very low permeability repairs will trap water beneath and thus can suffer frost or vapour delamination damage. The protection of reinforcement in concrete is based on the preservation of steel at high pH and the ability of cement to bind small amounts of chloride in the C_3A. If the substrate and repair material properties are not matched properly in repairs, then corrosion control can be difficult. Also, it is not easy in practice, to achieve sufficient cleaning and reliable coating of reinforcement so as to protect it from corrosion. For each repair scenario, proper evaluation of the electrochemical behaviour of local and potential macro-cell corrosion must be carried out, and improved techniques for evaluating chloride ingress and carbonation resistance also need to be applied to repair materials.

3 EXPERIMENTAL

3.1 Sample preparation

Four different concretes were used in testing the various types of repair materials. The concretes varied in both composition and age which allowed conclusions to be drawn about the effect of repair materials on young and old concretes. The different concretes were cured to 28 days or one year prior to application of the repair materials. Table 1 gives the concrete mix information.

Table 1 Concrete mixtures used in the investigation

	Water /binder ratio	Binder	Strength class (MPa)	Age of concrete
Mix 1	0.5	CEM 1 42.5N	40	28 days
Mix 2	0.65	CEM 1 42.5N	30	28 days
Mix 3 FA	0.5	CEM I 30% FA	60	1 year
Mix 4	0.5	CEM I 42.5N	-	1 year

Standard 100 mm concrete cubes were cast and subjected to the surface preparation techniques of cutting, brushing and chiselling. Cutting was done with the use of a diamond saw cutter while brushing was done using a wire brush with a controlled brushing technique (90 strokes per minute for 20 minutes). Chiselling was done using a standard chisel and hammer technique to break off 7 to 10 mm of the surface concrete. Once all the surfaces had been prepared, they were thoroughly cleaned with the use of a compressed air hose. This was done to ensure that substrates are clean and grit free before application of the repair materials. The various repair materials were then applied to concrete cubes according to manufacturer specifications. After the treatment, the repaired cubes were core-drilled to extract 70 mm diameter by 30 mm thick discs for durability index testing (see Section 3.2). The repair mortar treatment formed a uniform thickness of 8 to 10 mm on the test face of the prepared core discs. Also tested were the corresponding control concretes on which no repair materials were applied. The five generic types of repair materials used in the investigation were the general purpose mortar (cementitious), epoxy resin mortar (resistant to acids and alkalis), cement-based mortar (weather and crack resistant), masonry and carbothane aliphatic paints. The special properties of the repair materials are included in Table 2.

3.2 Test methods

The oxygen permeability and sorptivity indexes developed through a joint research program of the University of the Witwatersrand and University of Cape Town in the 1990's (Alexander et al., 1999) were used in this investigation. These methods are being used widely in the industry for quality control and are in the process of being drafted into national standards (SANS 516-1,2,3: 1999) .

Permeation is a term that describes the movement of fluids through the pore structure of concrete under an externally applied pressure. Permeability is therefore a measure of the ability of a material to transfer fluids. The oxygen permeability test is designed to measure the permeability of concrete using oxygen gas. The measured permeability can be used to attain knowledge about the pore structure that exists within the concrete. Oxygen permeability is also known to be directly related to carbonation and other mechanisms that lead to the deterioration of concrete over time (Alexander et al., 1999). An oxygen permeability index (OPI) value is calculated by taking the negative log of permeability. An OPI > 10 is classified to be concrete of excellent quality while a value below 9 is considered poor quality.

Absorption is the process whereby fluid is drawn into a porous, unsaturated material under the action of capillary forces. The capillary suction is dependent on the pore geometry and saturation level of concrete. Water absorption caused by wetting and drying at the concrete surface is an important transport mechanism but becomes less significant with depth. This action of wetting due to capillary forces is what is referred to as sorptivity. The sorptivity rate can be determined by use of the change in mass with respect to dry mass, the saturated mass, sample thickness and period of absorption. High quality concrete should have a sorptivity index value below 6 mm/hr$^{0.5}$ while any value above 10 mm/hr$^{0.5}$ is indicative of poor concrete quality.

4 RESULTS AND DISCUSSION

In this section, each repair material will be examined and discussed. The performance of each material in both the OPI and sorptivity tests will also be analysed. Bar graphs are used to illustrate the performances of the repair materials in the OPI test. Mixes 1 and 2 will be used to show the effects of surface preparation on permeability while Mixes 3 and 4 will be used to compare the performances of the various repair materials. During surface preparation, the cement-based mortar failed to adhere to the cut and brushed surfaces and was only able to bond to the chiselled concrete surface. Accordingly, no results could be generated for cement-based mortars applied to the cut and brushed concrete surfaces.

4.1 Permeability performance of repair materials

The results clearly show the benefit of applying the repair materials on permeability of concrete. Figure 1 shows that regardless of the type of surface preparation, significant reductions in permeability resulted in all the concretes whose surfaces were repaired with mortar or surface coating. Oxygen permeability reduced from 2×10^{-10} m/s in the control to about 5×10^{-11} m/s for general purpose mortar, and $< 5 \times 10^{-11}$ m/s for all other repair materials consisting of epoxy resin, masonry coating and carbothane aliphatic paint. Results show that use of the repair materials changed the OPI durability class of concrete samples from "Good" to "Excellent". The OPI in all the repaired concretes had excellent OPI values in the range of 10.10 to 10.35 compared to control whose values varied from 9.7 to 10 depending on the method of surface preparation.

Further examination of the data was conducted by determining the proportional changes in oxygen permeability of the various mixes under different methods of surface preparation. From Figure 2, it is evident that brushed surface preparation decreased permeability the most, giving greater than 75% decrease in permeability. The cut surface preparation lead to a 70% decrease in permeability whilst chiselled surface preparation yielded a 42% decrease for Mix 1 and a 65% decrease for Mix 2. It can therefore be concluded that brushed surface preparation is the best type of surface preparation for OPI when applying repair materials. The least performance by chiselled surface preparation may be attributed to possible microcracking of concrete resulting from mechanical damage induced during the chiselling operation. Considering that the gas flow during the OPI test is unidirectional, perpendicular to the plane of the test surface, it is interesting that the bond between the repair material and the substrate could influence permeability. It is possible that if a weak bond between the substrate and repair material exists, it may provide a preferentially lateral gas flow path thereby altering the pressure decay.

4.2 Sorptivity results

Line graphs are typically used to plot sorptivity results of the mass gained versus square root of time. The results of Mix 1 are presented in Figure 3 for each type of repair material and for each type of surface preparation. As previously mentioned, the cement-based mortar was only able to bond to the chisel surface, therefore its sorptivity results are only reported for the chiseled surface preparation. The paint repair materials did not absorb water and hence are not included in the graphs of Figure 3 showing sorptivity results for the chiseled, cut and brushed surface preparations respectively. Note that both scales of the graphs are the same.

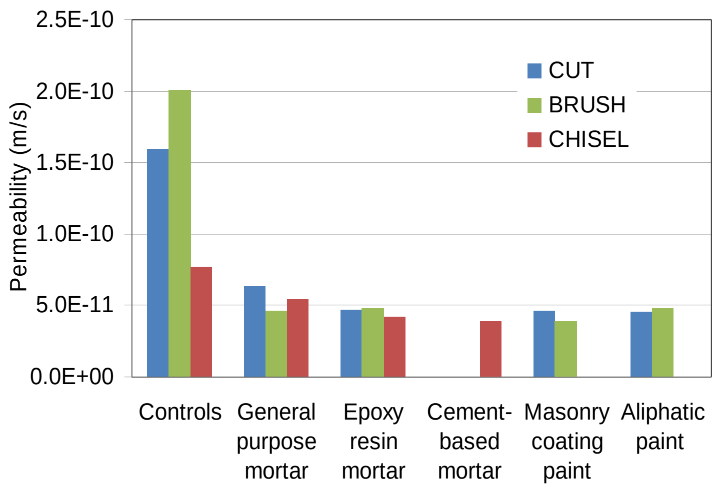

Figure 1 Oxygen permeability results for mix 1 as influenced by the various repair materials and surface preparation methods

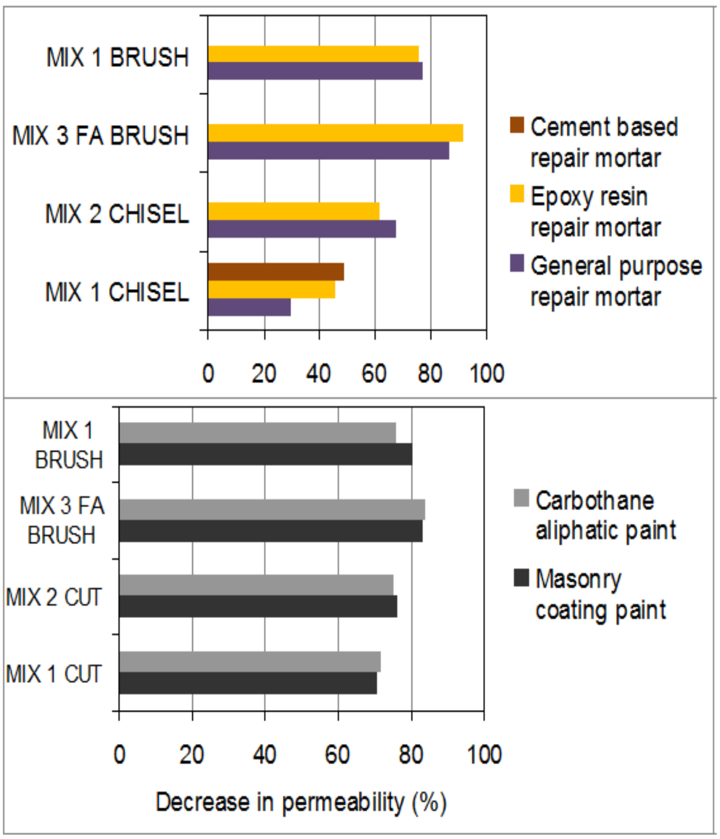

Figure 2 Decrease in oxygen permeability for various mixes and various surface preparation methods

From the graphs, it can be seen that the *epoxy resin mortar* performed the best as it absorbs the least water, followed by the *cement-based mortar* and the *general purpose mortar*. As expected, the control (with no repair material applied on) performs the least.

Quite a unique behaviour was observed with the epoxy resin mortar. This mortar characteristically tended to absorb water at certain intervals and then subsequently expels it. This process goes on recurrently and appears to exhibit hydrophobic behaviour (see Figure 3). Average result of sorptivity values are presented in Table 2 for the various repair materials. By virtue of the characteristics of paint-based coatings, they did not absorb water as expected, while the hydrophobic property of epoxy resin also prevented water absorption, as earlier discussed. Although the OPI test generates results in all the repair materials, the sorptivity test may not apply to paints and similar coatings, as no meaningful results can be obtained.

Table 2: Average sorptivity results obtained for the various repair materials

Repair material	Special qualities	Sorptivity ($mm/hr^{0.5}$)
Control	No repair applied	9.9
Cement-based mortar	Weather resistant	6.5
General purpose mortar	Similar to cement	7.6
Epoxy resin mortar *	Resistant to acids and alkalis	0
Carbothane aliphatic paint	Resistant to acids and solvents	0
Masonry coating paint	Resistant to alkali attack	0

*Hydrophobic

5 CONCLUSIONS

The general trend in results shows that repair materials significantly improve concrete durability through an increase in OPI values and a decrease in water absorption rate. A brushed surface gives the best result with over 75% decrease in oxygen permeability of concrete relative to the control, followed by the cut surface preparation, while chiselled samples gave the least favourable results presumably due to possible microcracking arising from mechanical action of surface preparation.

The epoxy resin repair mortar performed the best in both the OPI and sorptivity tests. It was found that this material has water-repelling qualities. The general purpose mortar showed good performance with the oxygen permeability test where it increased the OPI value significantly from 9.5 to 10.4. But the material did not perform as well in the sorptivity tests. Both the aliphatic and masonry paints showed similar decreases in permeability exceeding 70% for all different surface preparations and concrete mixes.

The cement-based mortar did not adhere to any of the surface preparations other than the chiselled ones but performed well in this category. It decreased permeability by 50% and was the second best performing material in the sorptivity test. With this repair material, it is evident that a rougher surface allows a stronger bond to form between the substrate and repair material.

The sorptivity test method may not be suited for use with repair materials of the paint coating type as these do not generate meaningful results.

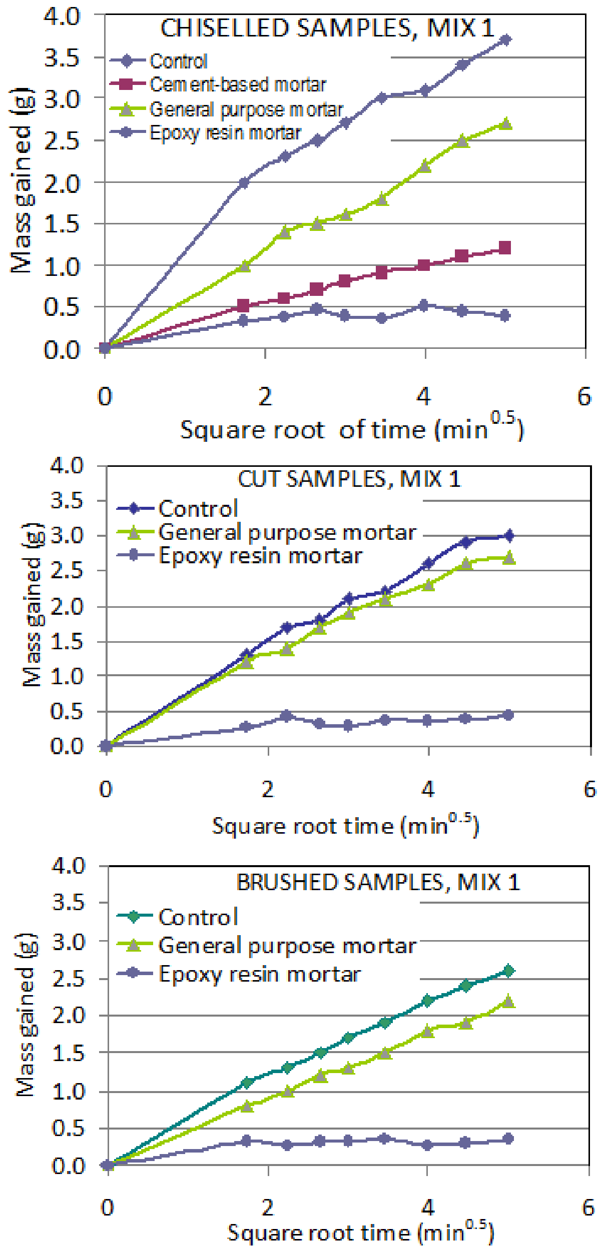

Figure 3 Sorptvity test results for chiselled, cut and brushed samples

6 REFERENCES

Al-Zahrani M.M, 2003 Mechanical properties and durability characteristics of polymer- and cement-based repair materials, *Cement and Concrete Composites*, 25, 527-537

Alexander MG, Ballim Y, Mackechnie JM, 1999 *Concrete durability index testing manual"* Research Monograph No. 4, Departments of Civil Engineering, University of Cape Town and University of the Witwatersrand, March 1999 31p

Almusallam A.A Khan, F.M. Dulaijan, S.U. Al-Amoudi O.S.B. 2003 Effectiveness of surface coatings in improving concrete durability, *Cement and Concrete Composites*, 25, 473-481

Momayez A 2005, Comparison of methods for evaluating bond strength between concrete substrate and repair materials, *Cement and Concrete Research,* 35, (4), *748-757*

Morgan D.R. 1996, Compatibility of Concrete Repair Materials and Systems, *Construction and Building Materials*, 10, (1), 57-67

SANS 516-1, 2, 3: 2009 (Draft Edition 1) Concrete durability index testing manual Part 1 - Preparation of test specimen; Part 2 - Oxygen permeability test; Part 3 - Water sorptivity test, SABS Standards Division

Wood J. G. M., King E.S, Leek D.S. 1990, Concrete repair materials for effective structural applications, *Construction and Building Materials*, 4, (2), 64-67