Polymer Cement Concrete (PCC) – of Interest for Concrete Block Paving?

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ABSTRACT
Polymer cement concrete (PCC) is a concrete polymer composite (CPC) where both cement paste and polymer serve as binders. PCCs are most frequently made by adding a polymer emulsion (i.e. latex) to the fresh concrete mix. The performance of (PCC) is reviewed with a special focus on properties for concrete block paving; both mechanical properties like abrasion resistance, impact resistance and tensile/flexural strength and durability related properties like freeze/thaw resistance, capillary suction and chemical resistance. Spesific examples for each of the properties are given and the relevance for concrete block paving is discussed. The importance of choosing the right principle for comparing the PCC with ordinary concrete, and the right type of polymer, are stressed. Depending on type of polymer, dosage of polymer and principle of comparison, a PCC material may provide properties of interest for concrete block paving; improved abrasion resistance, increased impact and tensile strength, improved freeze-thaw resistance, lower capillary suction and improved chemical resistance. The most cost/effective dosage of dry polymer in PCC is usually 10 % of the cement weight.

Key-words: Polymer cement concrete, PCC, latex, abrasion, freeze/thaw, capillary suction.

INTRODUCTION
Aircraft pavements demand the highest performance criteria of all concrete block paving applications. The criteria include durability, strength, stability, skid resistance, ride quality, water dissipation, maintenance requirements and resistance to thermal shock, fuel and oil-spills, and de-icing and anti-icing agents. At the recent paving of Luton airport, enhancements were made to the requirements of ASTM C 936 "Standard Specification for Solid Interlocking Concrete Paving Units". The project specifiactions had precise requirements for aggregate type, compressive strengths and tensile splitting strength to ensure superior performance. The compressive strength requirement of the samples at 28 days was identical with ASTM C 936; the average not less than 55 MPa with no individual unit less than 50 MPa. The tensile splitting strength requirement included a 28 day strength of not less than 4.5 MPa according to ISO 4108. To increase the durability of the pavers, absorption and freeze-thaw resistance requirements were also increased above the ASTM minimum. Freeze-thaw durability should comply with the specifications in CAN3-A231.2-M85 by the Canadian Specification Association. Water absorption was no greater than 5 % with no individual unit greater than 6 %, while 7 % is the maximum for an individual unit according to ASTM.

Note that when pavers are made by pressing concrete mixes of stiff consistency, most of the PCC materials described in the literature are free-flowing blends. However, there is no obstacles preventing PCC blends with low w/c to be produced analogous to pavers.

The most widespread method in literature /1/ of comparing different PCCs, or comparing them with a cement concrete (CC) reference, is to keep the flow constant. This approach is very practical, but, on the other hand, a number of factors are varied simultaneously (most important the water-to-cement ratio) to an extent where it is impossible to evaluate the direct influence of the polymer itself on the PCC performance.

In the later years, another method of comparison has been developed by Schorn /2/, comparing the polymer phase with a phase of non-binding capacity (i.e water). However, the author seems to have neglected the fact that adding additional water to a cement phase have significant effects on the paste; increasing the porosity (non-binding), but also increasing the degree of hydration (binding).

The author of the present paper prefer to compare the performance of the polymer phase with the performance of the cement paste itself, and the method of comparison has been utilized in a number of publications /3-13/. Thus, if there is no significant improvement by adding a polymer, it may be more cost-efficient to use a cement mortar with for instance plasticizer to reduce w/c. The present principle can be divided into three parts: **1)** The binder-to-aggregate volume (V) ratio should be kept constant by replacing a cement paste (cement and water) volume by an equal volume of polymer. Thus;

$$V_{Total\ binder} = V_{Cement} + V_{Water} + V_{Polymer} = Constant \quad (1)$$

It is of importance when for instance mechanical properties are to be tested (stress distribution) that the total binder/aggregate ratio is constant. **2)** The water-to-cement ratio, by mass (m) or volume (V) should be kept constant within each series. Thus;

$$m_{Water}/m_{Cement}\ (= w/c) = Constant \quad (2)$$

The quality of the cement paste is given by the w/c (e.g. degree of hydration, capillary porosity etc). This second criterion is of importance both for mechanical properties (total porosity) and diffusivity/permeability (open porosity). **3)** The air content of the mixes within each series should be kept constant. The air contant of PCC may vary significantly depending on which polymer is used. However, the air content may be controled by adding a suitable de-foaming agent.

The preceding discussion of PCC properties in relaion to concrete block paving is divided into mechanical and durability properties:

MECHANICAL STRENGTH

Since cement concrete (CC) inherently is a brittle material, the tensile and flexural (dominated by tensile stress) strengths may be improved by including polymers (e.g thermoplastics) in the binder. The abrasion process is dominated by tensile forces and may be strongly influenced by impact as well. Thus, these three mechanical properties are treated separately:

Abrasion resistance

The abrasion resistance of latex-modified mortar and concrete (PCC) depends on the type of polymer added, polymer-cement ratio and abrasion or wear conditions. In general, the abrasion resistance is considerably improved with an increase in polymer-cement ratio. Figure 1 illustrates the abrasion resistance of typical latex-modified mortars /14/ tested according to JIS A 1453 (Abrasion-paper method using a testing machine similar to Taber's abraser). Be aware of the possibility of clogging the paper with polymer when this method is used on PCCs. The abrasion resistance of a PCC with a polymer-cement ratio of 20 % increases by 20-50 times compared with an unmodified mortar (CC). Teichman /15/ found that PAE (i.e. polyacrylic ester) modified mortar with a polymer-cement ratio of 20 % had an abrasion resistance 200 times higher than convential mortar. Gierloff /16/ developed a traffic simulator for abrasion testing and showed that various PAE-modified concretes with a high polymer-cement ratio and a low water-cement ratio resisted traffic abrasion very well. Ohama's study /17/ of SBR (i.e. styrene butadiene rubber) modified mortars revealed that the abrasion resistence increased with the amount of bound styrene (i.e. increasing toughness) of the polymer.

Impact resistance

Latex-modified mortar and concrete has an excellent impact resistance in comparison with conventional mortar and concrete according to Ohama /1/. This is because polymers themselves have high impact resistance. The impact resistance generally increases with increasing polymer-cement ratio. However, the data of impact resistance vary markedly between testing methods reported by different workers. Figure 2 shows the impact resistance of latex-modified mortars measured as the falling height of steel ball at failure /18/. NR (natural rubber) and SBR (Styrene-Butadiene rubber) modified mortars with 20 % polymer of the cement weight gave an impact resistance of about 10 times greater than the unmodified mortar.

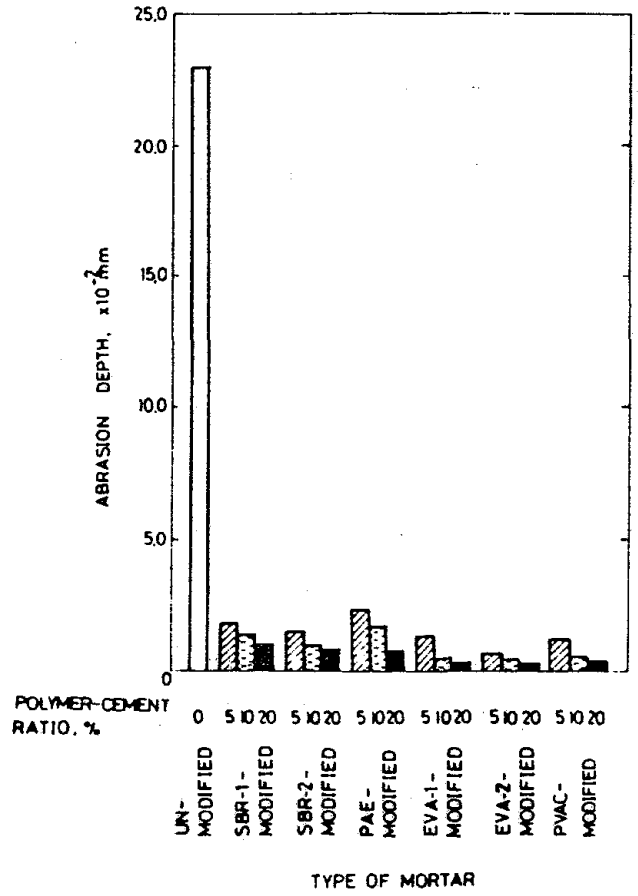


Fig. 1 Abrasion resistance of typical latex-modified mortars (PCC) with different dosages and types of polymer (SBR = styrene-butadiene rubber, PAE = Polyacrylic ester, EVA = ethylene-vinyl acetate copolymer, PVAC = poly vinyl acetate) /14/.

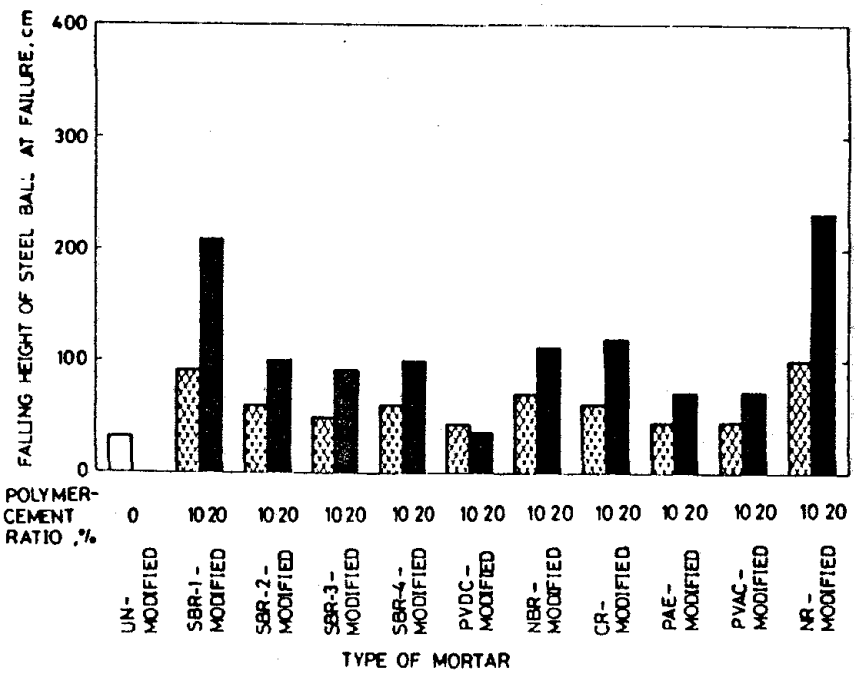


Fig. 2 Impact resistance of latex-modified mortars with different dosage and type of polymers (SBR = styrene-butadiene rubber, PVDC = polyvinylidene chloride, NBR = nitrile-t-butyl rubber, CR = chloroprene rubber, PAE = polyacrylic ester, PVAC = poly vinyl acetate, NR = natural rubber) /18/.

Tensile/flexural strength
In general, latex modified mortar and concrete (PCC) show a significant increase in tensile and flexural strengths, but no improvement in the compressive strength as compared to ordinary concrete or mortar (CC). This is interpreted in terms of the contribution of the high tensile strength of the polymer itself and the overall improvement in the aggregate-binder bond. The strength properties of the PCCs are influenced by a number of factors interacting with each other: The nature of components used (e.g. cement, latex, aggregate), the control factors for mix proportioning (e.g. polymer/cement, w/c, void/binder), curing methods and test methods /1/.

The effect of curing condition on the flexural strength of PCCs based on different dosage and type of polymers is revealed in Figure 3 /19/. Favourable curing conditions for PCC differ from that of CC because of the two phase binder with different properties. Optimum strength of the cement paste is obtained under wet conditions, whereas strength development in the polymer (i.e. added as latex) depend on a period where the composite dry out. PCCs based on latex may even loose some tensile strength when rewetted, but the strength is usually regained after a new period of drying out (unless the polymer is degraded during the wet period; like "saponification" of poly vinyl acetate).

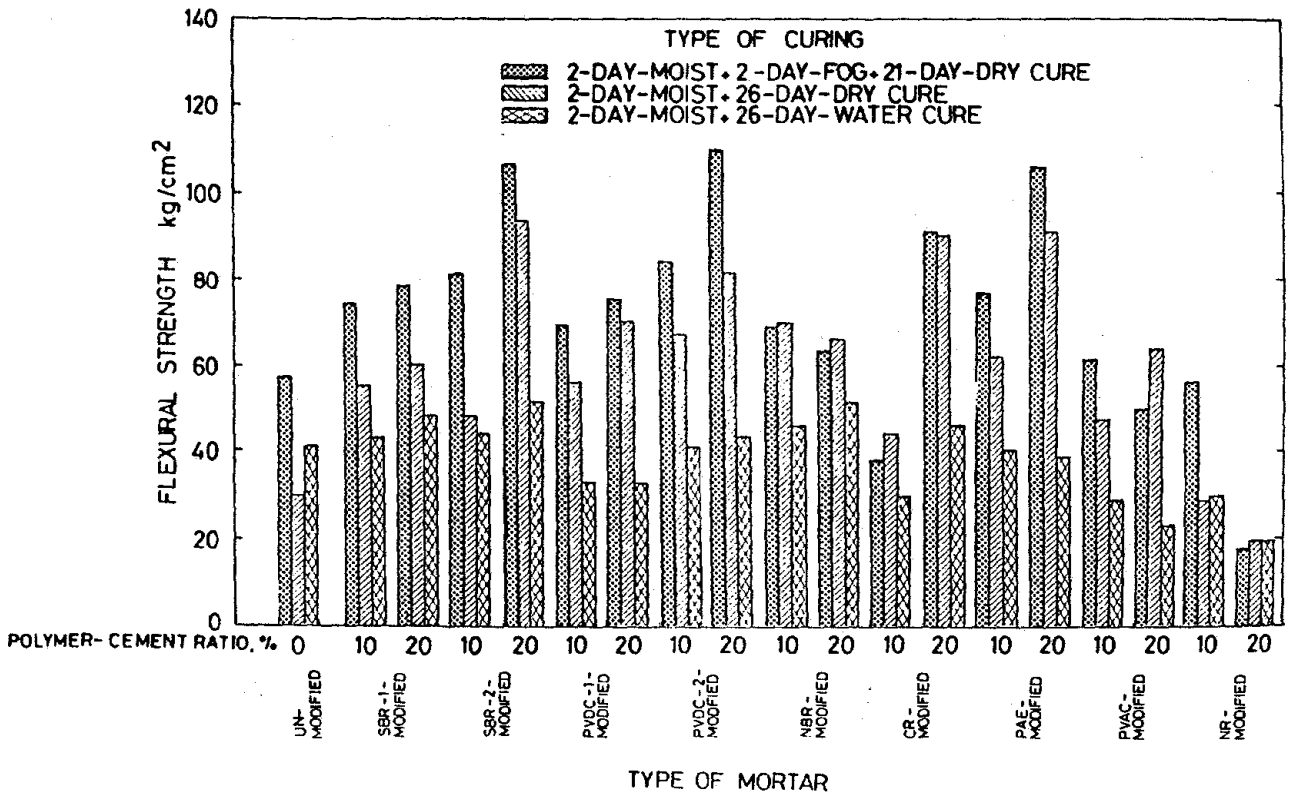


Fig. 3 Effect of curing conditions on flexural strength of PCCs based on different dosages and types of polymers (SBR = styrene-butadiene rubber, PVDC = polyvinylidenechloride), NBR = nitrile-t-butyl rubber, CR = chloroprene rubber, PAE = polyacrylic ester, PVAC = poly vinyl acetate, NR = natural rubber) /19/.

If the pavers are made with fibres, the adhesion between fibre and matrix may be enhanced by adding latex. Justnes et al /4/ increased the fracture energy of PAN (polyacrylnitrile) fibre reinforced mortars by adding different latexes. The effect was attributed to improved adhesion between fibre and matrix as revealed by SEM (scanning electron microscopy).

DURABILITY
The general improvement in durability of PCCs compared with CC is related to the hydrophobicity, the air-entrainment and the crack-bridging and -distribution ability promoted by the polymer phase.

Freeze-thaw resistance

Latex-modified mortar and concrete have improved resistance to freezing and thawing (i.e. frost attack) compared with conventional mortar and concrete (CC). This is partly due to the reduction of porosity as a result of decreased w/c-ratio (when the equal-flow principle is used for comparison), filling of pores with polymer and entrained air introduced by polymers and surfactants. Figure 4 represents the freeze-thaw durability in water (-18 to 4°C) according to ASTM C 666 of SBR (styrene butadiene rubber), PAE (polyacrylic ester) and EVA (ethylene-vinyl acetate copolymer) modified mortars /20/.

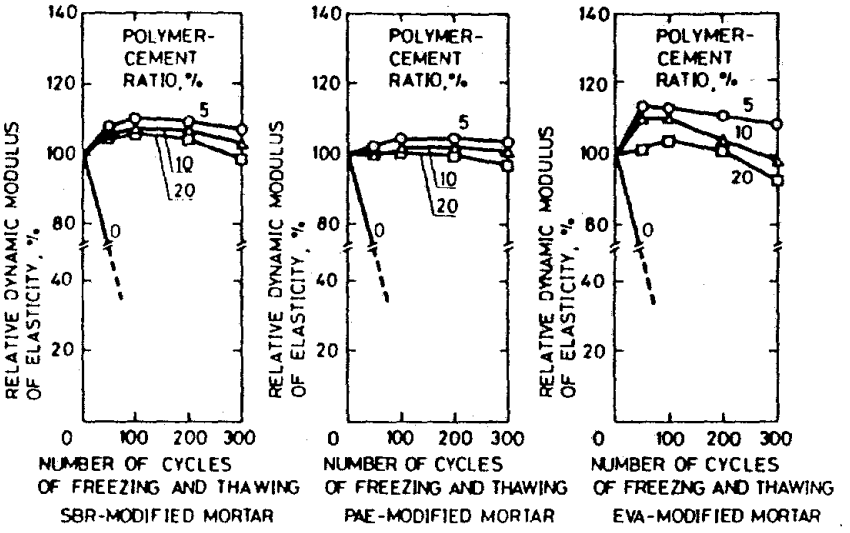


Fig. 4 Number of cycles of freezing and thawing vs relative dynamic modulus of elasticity of latex-modified mortars /20/.

Figure 5 shows the spalling (kg/m^2) of CC and PCCs with 10 vol% PAE of different composition as a function of number of freeze/thaw cycles (from +20 to -20 to +20°C in 24 h). The samples were tested according to the Swedish

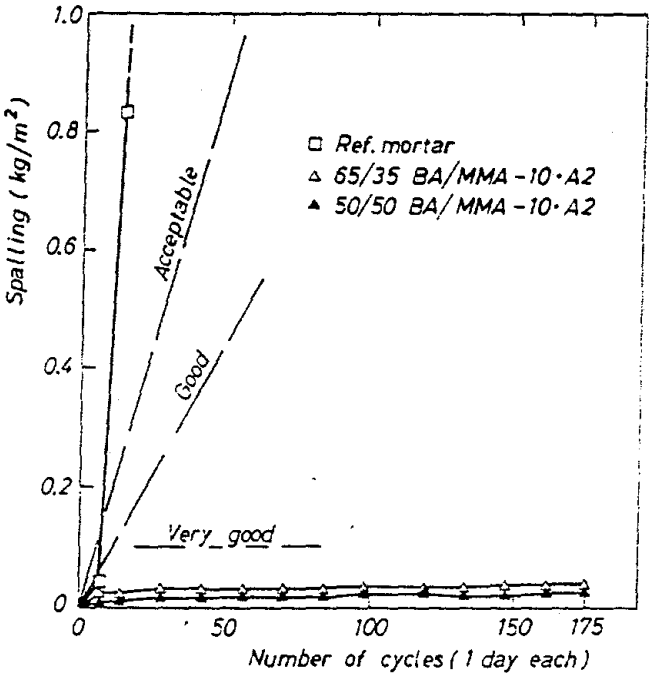


Fig. 5 The spalling (kg/m^2) of CC and PCCs with 10 % PAE of different composition caused by freeze/thaw action when exposed to 3 % NaCl.

Code SS 137236 with a single side exposure to a 3 % NaCl solution. While the reference mortar was rated "not acceptable", both PCCs were rated "very good" according to the method. Note that even though the total binder volume and w/c = 0.55 were constant, the air volume was higher in the PCCs.

Capillary suction

Many of the improved durability related properties of PCCs are caused by the general drier interior due to a decreased capillary suction combined with a relatively unchanged water vapor transmission /3/. The decreased water absorption by capillary suction is due to the hydrophobic nature of many polymers. Figure 6 reveal the capillary suction of discs of CC and PCC dried at 45°C for two weeks, for two different polymers at dosages ranging from 5-20 vol% of the total binder volume and a constant w/c = 0.40 (criteria 1 and 2 fulfilled in the preferred principle of comparison) /21/. Notethat 10 % PAE (PMMA/PBA = copolymer of methylmethacrylate and butylacrylate) seems to be twice as effective than SBR in reducing the water suction until 4 days, while the reference mortar is water saturated (= horisontal line) after one day.

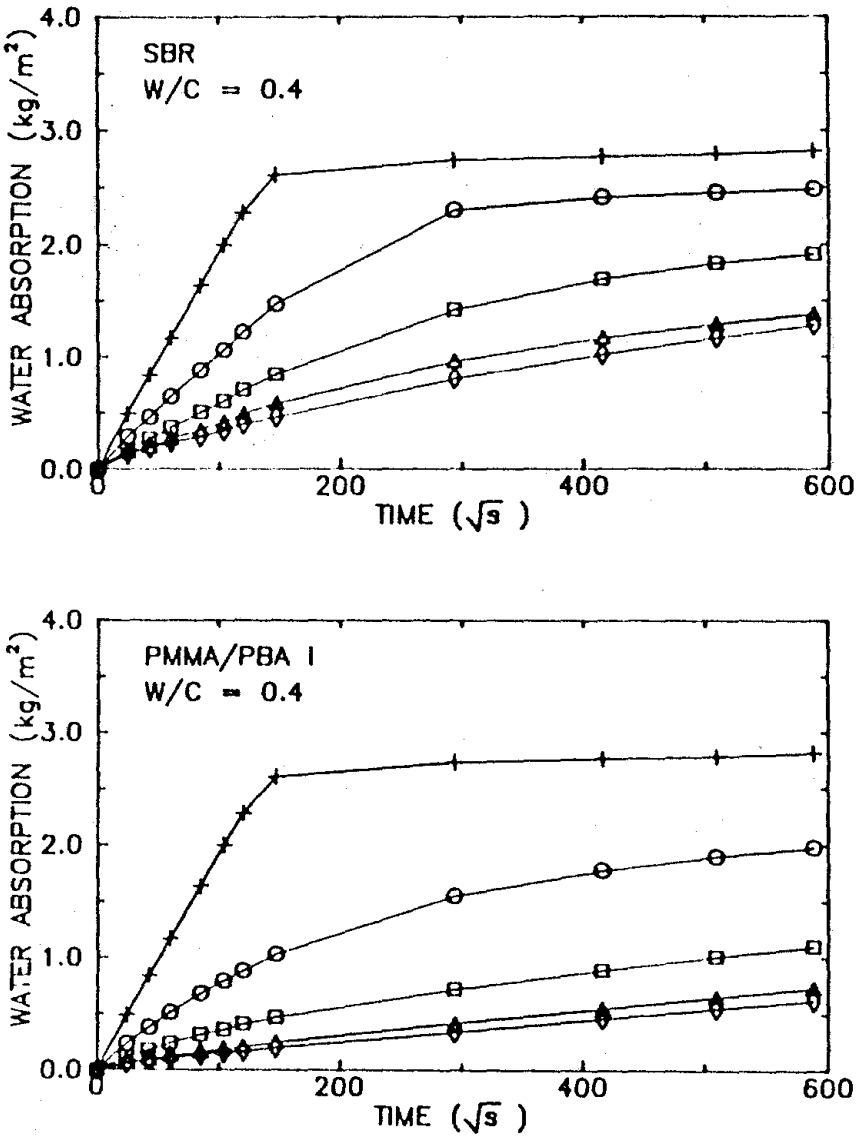


Fig. 6 The capillary suction of PCC with 0 (+), 5 (o), 10 (□), 15 (△) and 20 (◊) vol% SBR (upper) and PAE (lower) /21/.

Chemical resistance

The chemical resistance of latex-modified mortar and concrete (PCC) is dependent on the nature of polymers added, polymer-cement ratio and the nature of chemicals. Most PCCs are atacked by inorganic and organic acids and sulphates as they contain hydrated cement that is non-resistant to these chemicals, but resist alkalies and various salts /6, 8, 12/. The chemical resistance is generally rated as good towards fats and oils, but poor to organic solvents /1/. However, the latter depend on the type of polymer. NBR (nitrile-t-butyl rubber) modified mortar shows excellent resistance to organic solvents and oils, while NR (natural rubber) modified mortars do not resist these chemicals.

CONCLUSION

The properties of PCCs depend on type and dosage of polymer and the curing conditions. However, polymer additions to pavers may offer improvements in important performance characteristica like abrasion resistance, impact resistance tensile/flexural strength, freeze-thaw resistance and reduction in water absorption due to capillary forces. Among the type of polymers available as latexes, higher polyacrylic esters (PAE) generally have the best performance. However, regarding that a polymer dosage of 10 % generally is necessary in order to achieve significant improvements, and the price of the polymer compared to cement, the application of PCC in concrete paving is a matter of cost-efficiency.

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