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Effect of workmanship factors on traffic deck waterproofing coating systems

N. P. Mailvaganam and P. G. Collins

The protection that an elastomeric coating system provides is contingent upon how well and for long it functions in service. These performance characteristics are dependent not only on the material characteristics of the coating system but also on the quality of the installation. Poor on-site practices and indifference to quality control during the installation often produce a final product of dubious performance and durability. Problems that arise from poor workmanship are presented in this article.

The deck of a parking garage, in addition to serving as a structural diaphragm and wearing surface, must provide protection for the space below. Consequently the deck should be impervious to liquids, stopping water from seeping through cracks. Current waterproofing practice consists of sealing the top surface of the deck with penetrating sealers or elastomeric coating systems, *Fig* 1.

The protection that an elastomeric coating system provides is contingent upon how well and for how long it functions in service. These performance characteristics are dependent not only on the material properties of the coating system but also on the quality of the installation. Most systems consists of cold liquid-applied self-adhering elastomers that vary in chemical composition and method of application. Individual properties are governed by the manner and extent of the response of each material to the many site factors encountered in the installation. Although most coating systems are installed by licensed applicators trained by the manufacturer, poor on-site practices and an indifference to quality control during the installation often produce a final product of dubious performance and durability.

Application problems usually lead to pronounced defects which act as weak sites during the subsequent service life of the membrane[1,2]. Defective areas may be small and isolated, or large and occur throughout the deck. Areas of widespread defects - whether large or small - may require complete membrane removal. Defects can be present in numerous forms :

- uncured area (wet areas)
- over cured material (excessively hard)
- blisters
- delamination.

Installation problems can arise due to poor ambient weather conditions, the quality of the workmanship and the type of surface preparation of the substrate[3]. Problems that result from poor workmanship during coating installation are presented in this article.

Experimental procedure

Proprietary parking garage coating systems of the following generic types were investigated : C1 and C2 (two-component polyurethanes), C3 (catalysed one-component polyurethane) and C4 (two-component epoxy-urethane).

The effects of the following workmanship factors on coating performance were determined :

(i) poor mixing of coating components

(ii) presence of moisture on the concrete surface

(iii) mixing the coating components at low ambient temperatures

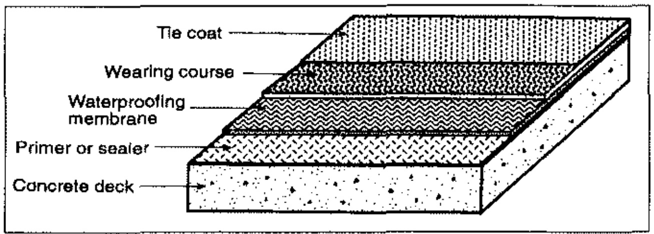

Fig 1 Cross section of an elastomeric deck coating system

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(iv) varying the time interval of application after mixing.

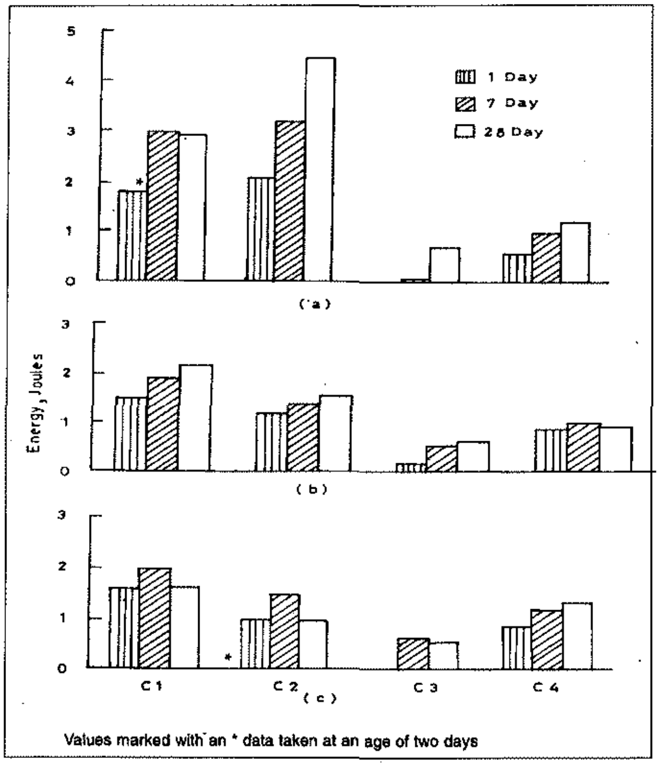
Poorly mixed samples were prepared by blending the resin and hardener, or catalyst, for one third of the manufacturers' recommended mixing times. Incorrect proportioning was used to simulate incomplete decanting of the components which would result in the wrong mixing ratios of the components being used. Samples were prepared with 15 percent excess of resin or hardener over the manufacturers' recommended mixing ratios. Changes in material properties were determined by testing free films cast on silicone release paper and cured under standard conditions (22°C, 50 percent relative humidity).

Moist surface conditions were produced by saturating the slabs with water for 24 hours and then allowing the substrate to attain a saturated surface dry condition prior to the application of the coating. Mixing at low ambient temperatures was done by conditioning components for 24 hours at temperatures between 5°C and 10°C prior to mixing and application. The effects due to delayed application were determined by increasing the time intervals between mixing and application of the mixed components by 15 minute intervals, upto a period of 45 minutes. After the installed coatings had cured for 28 days (under standard laboratory conditions), adhesion to the substrate was determined by the tensile pull-off test method.

Effects due to differences in surface preparation were evaluated by determining the changes in the adhesion of the membrane to the concrete substrate. Three techniques --- water-jet blasting, sand blasting and shot balsting were evaluated. The surface of a 1220 mm x 1830 mm (4" x 6") concrete slab was prepared using each method and was subsequently cut into 150 mm x 300 mm specimens. Samples of each membrane and primer (where specified) were then applied to the specimens. After 28 days of curing under standard conditions, adhesion to the substrate was determined by the tensile pull-off test method.

The tests employed in the investigation are given below.

- Tensile strength, percent elongation, energy required to rupture the system were determined as per ASTM D412 at 1, 7 and 28 days, on an *Instron Model 1122* Universal Testing Machine.
- Water vapour transmission, permeability and permeance were determined after curing for 28 days under standard conditions using ASTM E96, "wet cup" method. The comparison of the water vapour



Values marked with an * data taken at an age of two days

Fig 2 The effect of proportioning on energy to rupture (in Joules) for samples containing *(a)* excess resin *(b)* correct proportions and *(c)* excess hardener.

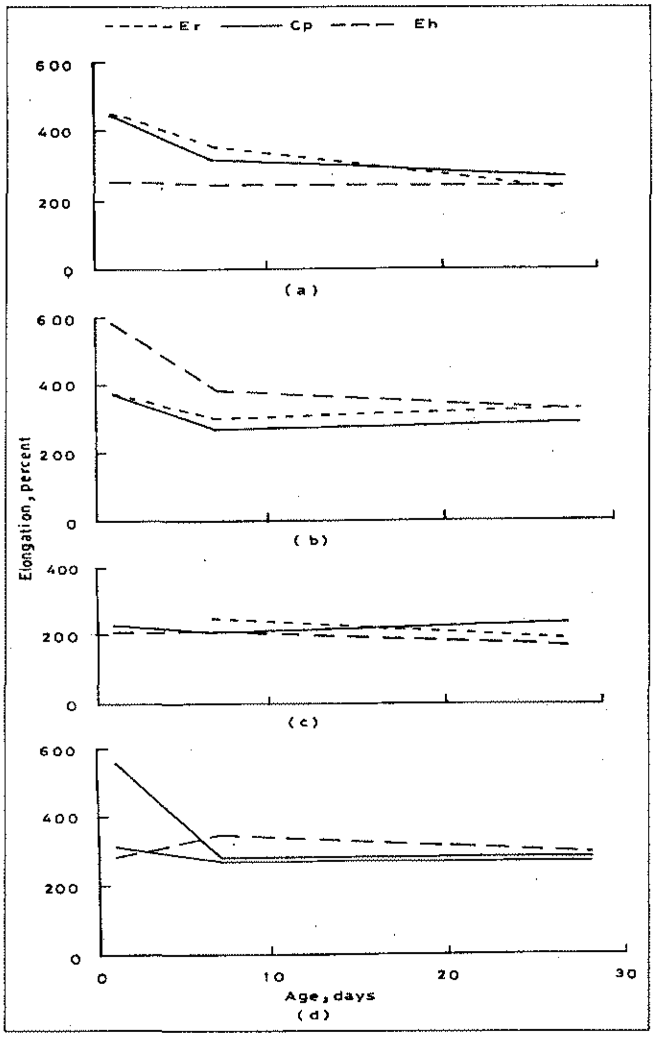


Fig 3 Development of elongation with age under mixing conditions of excess resin (ER), correct proportions (CP) and excess hardener (EH) for C1 *(a)*, C2 *(b)*, C3 *(c)* and C4 *(d)*.

transmission properties of the membranes was based on an empirical value of permeance in order to minimise the variation owing to differences in sample thickness. Permeance was calculated using the average permeability and the average thickness of the membrane samples

Calculated permeance = average permeability ×
average thickness

- Adhesive bond strength of the membrane to the substrate concrete was determined in accordance with ASTM D4541, using a pneumatic adhesion tester. For each specimen, average bond pull-off strengths were obtained by testing four 50 mm diameter aluminium dollies affixed to the cured membrane with an epoxy adhesive.

Results and discussion

Incorrect proportioning

Energy to rupture : Energy to rupture measures the amount of work required to rupture the sample and is calculated as the area under the load-deformation (stress-strain) curve. It can be used to evaluate the potential performance of a system. In general, a high energy system is likely to perform better for a longer period than a low energy system. Energy to rupture values for samples prepared with incorrect proportions are presented in *Fig* 2.

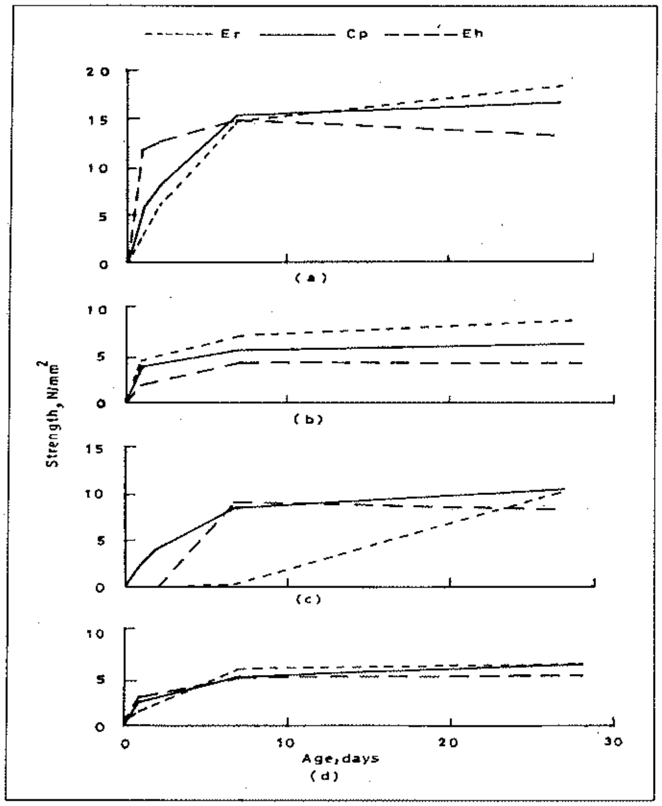
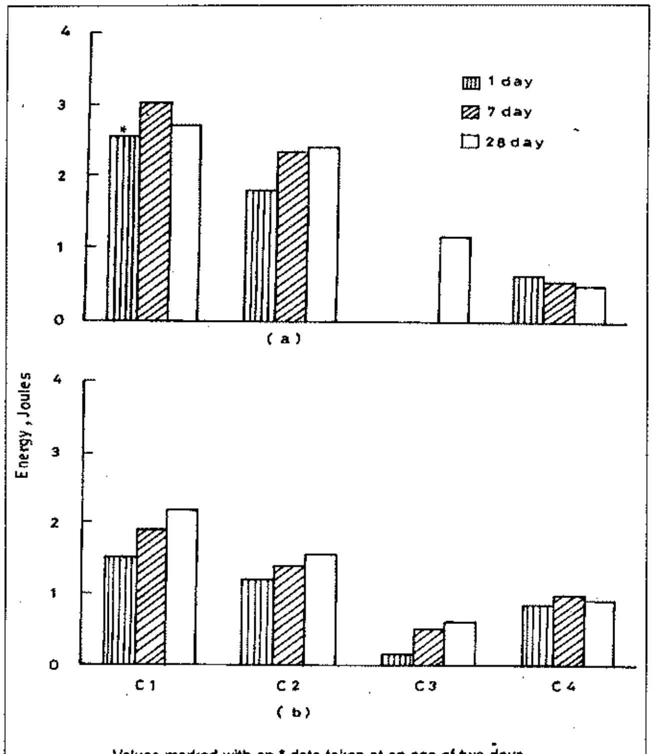


Fig 4 Development of tensile strength under mixing conditions of excess resin (ER), correct proportions (CP) and excess hardener (EH) for *(a)* C1 *(b)* C2 *(c)* C3 and *(d)* C4

Excess resin in the mixes of two of the systems (C1 and C2) produced dramatic increases in energy to rupture values at all ages. Twenty eight day values for C3 and C4 were similar to those obtained for correct proportions. However, for C3, one and seven day values indicated a severely retarded rate of cure. The use of excess hardener produced one and seven day values similar to those obtained with correct proportioning of the mixture for all membrane systems. At twenty eight days, however, all coatings except C4 produced energy to rupture values lower than those obtained with correct proportioning. Values higher than normal were obtained for C4. Although the values obtained for the four systems are not alarming (with the exception of the 1 day cure for C3), the significant variation in values because of incorrect proportioning warrant concern for the long term crack bridging characteristics of the coating system.

Elongation : The elongation capacity for samples prepared with excess amounts of resin and hardener, as well as those prepared at the correct proportions, are shown in Fig 3. Excess resin generally produced higher values initially and in some cases, showed a trend of decreasing values with age. The use of excess hardener showed a similar trend with age. Although twenty eight day elongation values were only slightly altered, the variation upto 7 days was more pronounced. Due to the severe retardation of cure for C3 when excess resin was used, only the twenty eight day value was obtained. The increased values at early stages of curing for excess resin mixes may result from the plasticising action of uncured resin particles, while the trend of decreasing values observed in some systems



Values marked with an * data taken at an age of two days

Fig 5 The effect of reduced mixing time on energy to rupture with *(a)* reduced mixing time and *(b)* correctly mixed samples

with excess hardener could be explained by the increased crosslinking of the polymer[1,4,5].

Tensile strength : Tensile strength development for samples with excess amount of resin and hardner are shown in *Fig 4*. The use of excess resin resulted in increased twenty eight day values and a trend of increasing values after twenty eight days for C1 and C2. A markedly slow rate of cure upto the age of twenty eight days was noted when C3 was prepared with excess resin. The use of excess hardener resulted in an initial increase and subsequent decrease in tensile strength values at twenty eight days. For coating C2, the use of excess hardener resulted in decreased tensile strength values at all ages.

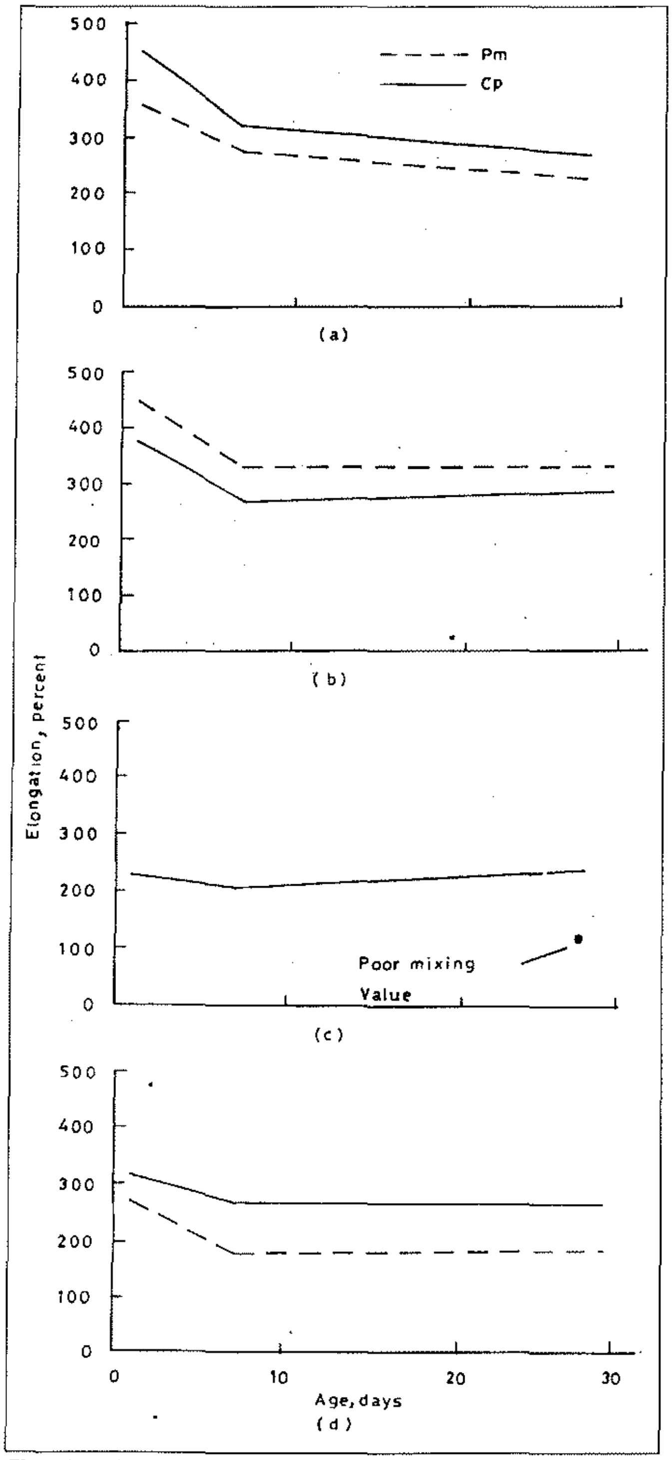


Fig 6 Development of elongation under poor mixing conditions (PM) and correct mixing conditions (CM) for *(a)* C1 *(b)* C2 *(c)* C3 and *(d)* C4

Tensile strength plays an important role in the tear resistance of the membrane[6,7]. Therefore, the severe retardation of cure observed in C3 is worrisome because of the possible damage that can occur during the post-installation construction activity. The trend of increasing values observed for C1, C2, and C3 when excess resin is used is also of concern because of possible reduction in long term crack-bridging capability.

Water vapour transmission : The average permeabilities and calculated average permeances of each waterproofing

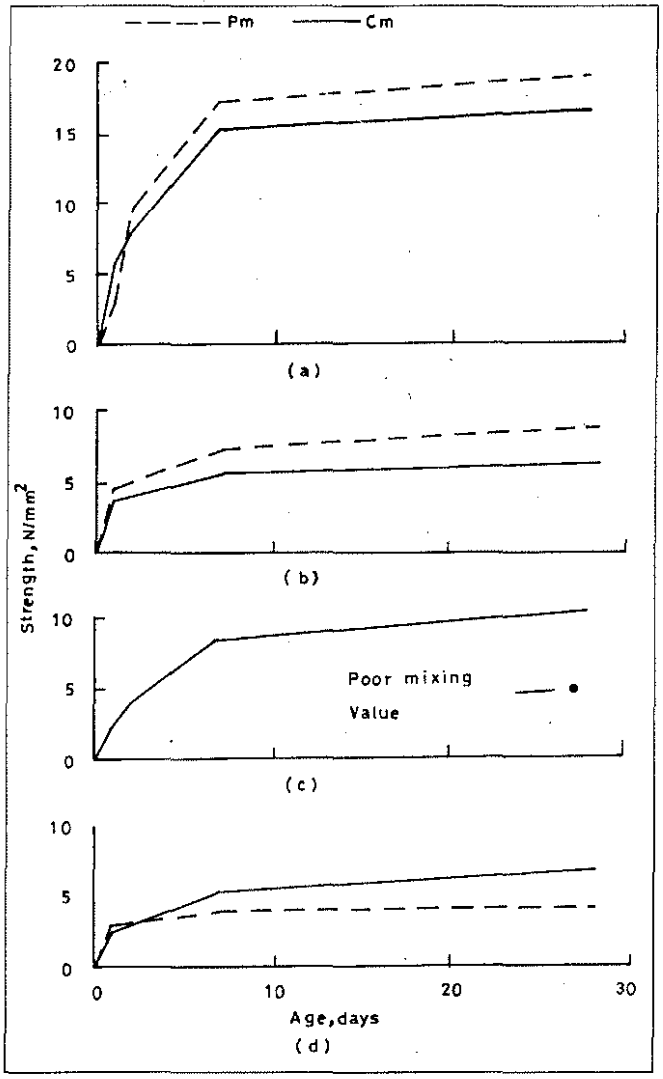


Fig 7 Development of tensile strength under poor mixing conditions and correct mixing conditions for *(a)* C1 *(b)* C2 *(c)* C3 and *(d)* C4

Table 1 : Effect of mix proportioning on permeability and permeance of waterproofing membranes

System	Permeability, (× 10^{-10} g/Pa-s-m)			Permeance, (× 10^{-7} g/Pa-s-m^2)		
	Excess resin	Correct proportions	Exces hardener	Excess resin	Correct proportions	Excess hardener
C1	1.28	1.11	1.05	2.51	2.17	2.06
C2	3.95	2.35	1.65	4.20	2.50	1.76
C3	0.97	0.44	0.7	2.20	1.00	1.52
C4	1.69	1.33	1.3	1.82	1.43	1.40

membrane determined by water vapour transmission studies are presented in *Table* 1.

Small changes in permeability were observed for C1 when the mix proportions of the components deviated from the manufacturers' stipulations; excess resin resulted in an increase, while excess hardener yielded a decrease in permeability. Changes in the permeability of C2 were significant: excess resin yeilded a very large increase while excess hardener resulted in a significant decrease in permeability. Both excess resin and hardener yielded increases in the permeability of C3, with excess resin producing the largest increase. Excess resin in the mixes of C4 resulted in a significantly higher permeability, whereas the use of excess hardener produced no change in permeability. Although the changes caused by the use of excess hardener in the mix were varied, the magnitude of the change was not as great as those caused by excess resin, which caused a significant increase in the permeability and permeance for C2 and C3.

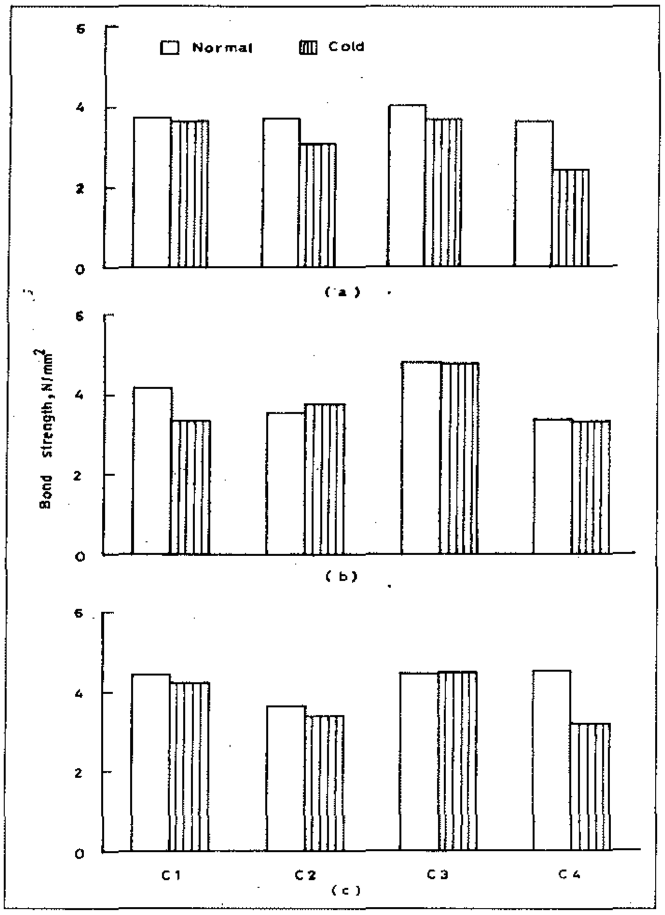


Fig 8 Effects of mixing at cold temperature on membrane bond strengths for different methods of surface preparation *(a)* shoshotblasting *(b)* sand blasting and *(c)* water jet blasting

Reduced mixing time

Energy to rupture : The energy of rupture for poorly mixed samples is presented in *Fig* 5. Values obtained at 28 days show that reduced mixing time produced an increase in the energy to rupture for all membranes, except for C4, which exhibited a decrease.

Elongation : The elongation capacity for poorly mixed samples is presented in *Fig* 6. Reduced mixing time generally produced lower elongation values than correctly mixed samples at all ages for most coatings. Larger decreases were observed between 1 and 7 days but thereafter, only small changes were noted. Poorly mixed samples of C3 did not adequately cure in the first seven days and therefore, only the twenty eight day samples were tested.

Tensile strength : The results of tensile strength developed for improperly mixed samples are given in *Fig* 7. Reduced mixing of the components of C1 and C2 resulted in tensile strengths that were greater than those noted for properly mixed samples at all ages, while the tensile strengths of poorly mixed samples of C3 and C4 gave decreased values at most of the ages investigated. The variation from designed values warrants concern with respect to such properties as tear resistance (for C4) and crack bridging (for C1 and C2).

Water vapour transmission : The average permeabilities and calculated average permeances resulting from poor mixing are shown in *Table* 2.

With the exception of C2, poor mixing of coating components produced an increase in both the permeability of the coating (a material property) and its permeance (a measure of performance). C4 and C3 produced large increase in permeance. The changes seen in C1 appear to be marginal. As stated previously, variation in this critical property underscores the need for proper mixing.

Mixing at cold temperatures

The effects on bond strength due to mixing coating

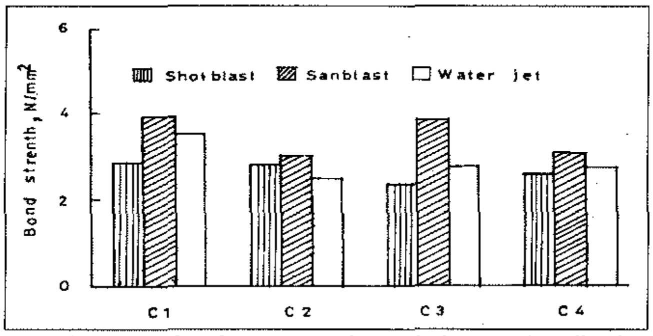


Fig 9 The effect of surface preparation technique on the adhesive strength of membrane samples to concrete

Table 2 : Effect of mixing on permeability and permeance of waterproofing membranes

System	Permeability, (× 10^{-10} g/Pa-s-m)		Permeance, (× 10^{-7} g/Pa-s-m^2)	
	Poor mixing	Correct mixing	Poor mixing	Correct mixing
C1.	1.21	1.11	2.37	2.17
C2	2.20	2.35	2.34	2.50
C3	1.64	0.44	3.73	1.00
C4	1.96	1.33	2.10	1.43

components at cold (10°C) temperatures are presented in *Fig* 8. In general, mixing at lower temperatures resulted in slight decrease in the adhesion values compared to those obtained from samples mixed at normal temperatures. Slight variations in bond strengths were also observed for the different methods of surface preparation. Jet blasting appeared to give the best results.

Surface preparation

The influence of surface preparation technique on the adhesion of the coating to the substrate was ascertained by changes in bond strength values. Concrete slabs prepared by the three commonly used techniques produced widely different surface profiles; water jet blasting gave the smoothest surface, sand blasting gave a lightly textured surface, and shot blasting gave a coarsely textured surface. The effects of variation in surface preparation technique are shown in *Fig* 9.

Shot blasting produced the lowest values, while sand blasting gave the highest values and water jet blasting was in the intermediate range. The effects observed here are consistent with the work of other researchers, who have noted that shot blasting leaves a fractured surface that is susceptible to delamination arising from tensile stresses (such as those induced by shrinkage of the polymer)[8,9]. The fractured surface, unless removed by a mild sand blast sweep, may lower bond strength.

Effect of surface moisture

Results showing the effects of substrate surface moisture on the adhesion of membranes to concrete surfaces are presented in *Fig* 10. These effects appear to be dependent on coating composition and type of surface preparation. Surface moisture on shot blasted surfaces produce decreased bond values for all coatings as compared to those values obtained from drier surfaces. Sand blasted surfaces containing surface moisture also showed a similar pattern for three of the coatings. C2 was the exception, producing slightly higher values when surface moisture was present, indicating that it was insensitive to surface moisture when the concrete substrate was sand blasted. Surface moisture on water jet blasted surfaces did not appear to inhibit adhesion. Three of the membranes had higher values than those obtained under dry conditions. Even though the adhesion of C1 decreased on a wet substrate, the resultant value when the surface was jet blasted was still higher than those values achieved with the other surface preparation techniques.

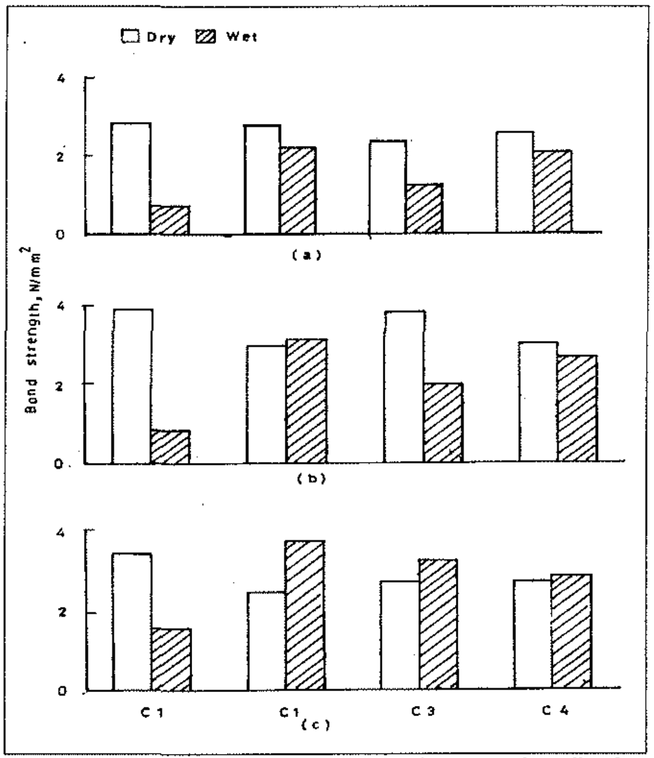


Fig 10 The effect of substrate surface moisture on the adhesive strength of waterproofing membranes to *(a)* a shot blasted surface *(b)* a sand blasted surface and *(c)* a water jet blasted surface

Effects of delays in application time

Bond strengths obtained when membrane application was delayed are shown in *Fig* 11 for three different methods of surface preparation. In general, there was a pattern of decreased adhesion as the time interval between mixing and application was increased. Surface preparation technique and delay in application time affected C3 the least and C1 the most. The magnitude of the reduction in adhesion values, however, was not large for the period investigated.

All coatings, except C3, exhibited a decrease in adhesion to a shot blasted surface when the time interval between mixing and application was increased. The time and extent to which adhesion decreased, however, varied for each system. C1 and C2 showed decreases after 15 minutes, whereas C4 began to decrease after 30 minutes. The adhesion of C3 initially increased with time, peaking after 30 minutes.

All systems, except C2, exhibited a loss of adhesion with an increased delay time prior to application on a sand blasted surface. The rate of decrease in adhesion was varied for the membranes. For C1 and C4, there was a decrease after 15 minutes, but the values obtained after 30 and 45 minutes were similar. In contrast, the adhesion values of C3 began to decrease after 30 minutes. An increase in the adhesion of C2 to sand blasted concrete was observed after a 45 minute delay in application.

A general trend of decreasing adhesion values was obtained for all membranes on a water jet blasted surface. For C1 and C3, decreases began after a 30 minute delay, while for C2 and C4, decreases began after 15 minutes.

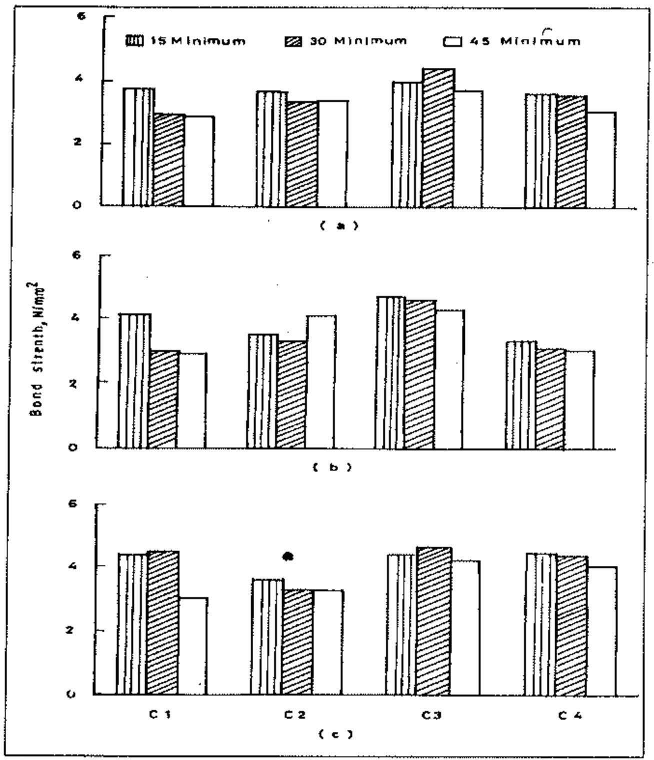


Fig 11 The effect of delayed application time on the adhesive strength of waterproofing membranes for *(a)* a shot blasted surface *(b)* a sand blasted surface *(c)* a water jet blasted surface

Conclusions

1. Although most systems were affected by many of the factors investigated, the C3 system showed that it was especially prone to site abuse, particularly at early ages.
2. It is important to adhere to a manufacturers' stipulated mixing proportions. Deviations from the stoichiometrically designed mixing ratios can have serious effects on both the mechanical properties of the coating and it's waterproofing character. Catalysed, single component systems are quite prone to variations in proportioning and mixing since they rely on complete dispersion of the proper amount of catalyst to initiate the curing reaction. If this does not occur, the material performances may be severely compromised. The effects of proportioning and mixing two-component systems are varied and depend upon the chemistry of the components. Since waterproofing character is a primary requirement of parking garage coating systems and the variation in values observed is significant enough to impair the long term performance, it is imperative that applicators ensure that on-site proportioning is carefully done.
3. The time interval between mixing and application of the coating affects the degree of adhesion to the concrete substrate. The optimal time interal after mixing is less than thirty minutes. Exceeding this interval results in significant decreases in adhesion values.
4. Poor mixing of coating components appears to have a significant effect on elongation capacity, which governs crack-bridging character. Since this property influences ability of a coating to remain functional in the parking garage environemnt, the importance of site supervision to ensure proper mixing cannot be over emphasised.
5. Sand blasting and water jet balsting, although yielding different surface profiles, performed similarly. The lower values obtained with shot blasting are probably a result of the fractured near surface that remains after surface preparation by this method.
6. The shot blasting technique produced a very rough surface texture, with a profile ranging from 0.4 to 2 mm. Since some of the recommended coating thickness fall below this profile, its use with very thin coatings should be reviewed. Furthermore, certain coatings, when placed in layers that are thicker than recommended, have a tendency to foam.
7. The effects of surface moisture appear to be dependent upon the type of coating used and the substrate texture produced by surface preparation. The surface profile produced by the water jet blasting reduced the membranes' sensitivity to surface moisture in comparison to the other two methods of surface preparation.

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