Use of Alternative Aggregates and Aggregate Gradings in Trowel-Applied Polymer Concrete Floors

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Synposis:

New Zealand has a predominantly agricultural-based economy, and consequently a heavy investment in processing buildings such as export abattoirs and dairy factories. Component failures in such plants can have a serious effect on production and profitability. Over the past ten years the Building Research Association of New Zealand has carried out an extensive research programme on flooring materials for abattoirs, investigating properties both in the laboratory and in use.

In the course of these investigations, it became clear that the formulation of commercial polymer concrete toppings, which are widely used, could be improved: in particular, reduction of the resin content below the common figure of around 20% by weight, and alternative aggregate sources to the limited supply of light-colored quartz and quartzite sands were sought. It was necessary that new, alternative mixes could still be applied by trowelling, the traditional method.

By starting from the aggregate grading curves of Weymouth (17), and BS 882(3), and using gap-grading, it was possible to lower the resin content to 10% or less and still retain trowellability, whilst using aggregates from the traditional sources. Alternative sources of aggregates, such as sandstone (greywacke) and basalt, were found which could be used to produce the light-colored floors considered to be necessary for hygiene reasons by the industry.

The experimental polymer concrete floor toppings were tested for the necessary mechanical properties (compressive strength, abrasion and impact resistance) for abattoir use.

Keywords: abrasion resistance; absorption; acid resistance; aggregates; basalt; compressive strength; corrosion resistance; costs; epoxy resins; floor toppings; gap-graded aggregate; impact resistance; industrial buildings; polyester resins; polymer concrete; workability

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INTRODUCTION

New Zealand has a predominantely agricultural-based economy, and consequently a heavy investment in processing buildings such as export abattoirs and dairy factories. Some of these facilities are large - for example abattoirs capable of processing 30,000 sheep per day. Component failures in such plants can have a serious effect on production and profitability. Floors in many of these plants are exposed to harsh environments in which they are expected to withstand both mechanical wear and tear and resist chemically corrosive substances. This is a particular problem for the meat and dairy industries.
Mechanical wear-and-tear is due to traffic, such as forklifts and trolleys, and impact damage from falling objects. Chemical corrosion can result from the use of specific chemicals in processing plants, such as sulphuric acid in fellmongeries, or corrosive wastes and by-products, such as lactic acid in milk (14).

Portland cement concrete (PCC) has a record of poor performance under such conditions. It is attacked by acids (most food wastes are acidic) and affected to some degree by virtually all food products and food wastes. To overcome these drawbacks a variety of hardwearing, chemically resistant topping systems have been developed to protect concrete floors in such situations. One of the most popular and effective has been polymer concrete flooring systems.

The main drawback with polymer concrete (PC) systems is their cost, which adds an extra \$NZ 30 - \$NZ 50/m^2 on top of the basic concrete floor. The study described here was initiated in an attempt to identify any areas where the formulation of commercial polymer concrete toppings could be improved. Emphasis was placed on reducing resin content from commonly used figures of 15 to 20% by weight and finding alternative aggregate sources.

AGGREGATE GRADING TRIALS

An analysis of commercial PC samples by pyrolysis at 550°C was carried out between 1981 and 1983. This showed that the resin content ranged between 16 to 22% by weight (10). A sieve analysis of the aggregates from the pyrolysed samples showed that most were continuously graded and could be fitted into one of the fine aggregate zones described in BS 882:(3). This grading type has been successfully used to make PCC for many years.

Ideally, the aggregate when mixed with the matrix (water, cement and fine sand) forms a concrete with each aggregate size uniformly distributed throughout the mix, the voids between the larger particles being filled by smaller particles and the matrix. An input of energy is required to move smaller particles past larger ones and achieve a uniform mix. In PCC this energy is provided by rodding and vibration. The lubricating properties of the water-cement-fines mix also assist the movement.

Polymer concretes are made with resins which are viscous and hence have much less lubricating ability than the matrix of PCC; furthermore, in the case of hand applied trowelled toppings little compactive effort is available. Maximising the workability of aggregate mixes is therefore essential if PC mixes with lowered resin contents are to be produced.

Variations in aggregate grading can significantly affect the workability of mixes. Two situations in particular are:

1) Where an aggregate contains an excess of any particular fraction
2) Gap-grading

The first case, which has been described as particle interference by Weymouth (17), can cause segregation by particle size (6) which is not eliminated by compaction. Ehrenburg (7) has published information on aggregate mixes designed to eliminate particle interference.

Gap-grading is the term used to describe aggregate mixes which are missing one or more aggregate sizes from a sieving regime. A single gap-graded mix has similar energy requirements to continuously graded aggregates. However, with double gap-graded mixes the energy requirement is lower (i.e. less dependance on lubrication and better workability).

Several workers (5,8,9) have reported that PCC made with gap-graded, and more especially double gap-graded aggregates, has better workability than mixes with identical water and cement contents but made using continuously graded aggregates. Thus gap-grading appeared to be a method whereby resin content could be lowered in polymer concrete mixes while still maintaining adequate workability for trowel application.

EXPERIMENTAL METHOD

Aggregate used in the grading trials was obtained from two sources. The larger sizes (2.4-0.3mm) were rounded quartzite and the smaller sizes (0.3-0.075mm) silica sand. Both were available and used commercially. Two proprietary resins were used, a polyester and an amine cured epoxy.

The aggregate was dried in an oven at 105°C for 18 hours then separated into fractions of +2.4mm, -2.4 to +1.2mm, -1.2 to +0.6mm, -0.6 to +0.3mm -0.3 to +0.15mm, -0.15 to +0.075mm. The +2.4mm fraction was not used.

Resin was premixed with hardener then added to the aggregate. Quantities less than about 1.5 kg were mixed by hand. Larger quantities were mixed with a mechanical mixer of approximately 20 litre capacity. The polymer concrete mixture was spread on concrete slabs (300x300x50mm) in a 6 to 8mm layer, screeded, then trowelled with a steel float. The PCC base slabs were acid etched then wire brushed to remove residues before the topping was applied. Cylindrical moulds 60mm high and 30mm in diameter were filled for compressive strength tests (10).

Abrasion resistance was measured as described by Sharman (13). Impact tests were carried out essentially as described by Sharman and Cordner (16). Water absorption tests were carried out as described in ASTM C413 (2) except that the moulds were 27mm high and 27mm in diameter. Adhesion of the polymer concrete topping to the PCC base was measured by a pull-off method. Samples for adhesion testing were prepared by cutting 40mm x 40mm x 40mm cubes from PC topped PCC slabs. Steel dollies were attached to the topping surface and the bottom of the cube with epoxy adhesive. A Dartec M1000 RE universal testing machine with a cross-head speed of 0.5mm/min was used to determine the tensile failure strength of the samples. Compressive strength was measured according to the method of MacGregor and Sharman (11), which is based on ASTM D695 (1).

RESULTS

12% Resin--Initial mixes were made with 12% resin by weight. The aggregate gradings are shown as A through G in Table 1. Table 2 lists compressive strength and water absorption values for these mixes. The results of abrasion tests on some of the mixes are shown in Table 3.

All the 12% resin mixes except G produced acceptable toppings with sealed non-porous surfaces. Although the difference was small, the double gap-graded mixes proved easier to mix than the single and non-gap-graded ones. Grading B produced the most resin-rich mix, but the decreased quantity of fine aggregate in this mix compared to grading A resulted in increased difficulty in achieving a satisfactory surface finish. Mix G proved impossible to trowel and resulted in a porous mass. This is a result of insufficient matrix (fine aggregate and binder) to fill the voids between the larger particles. Evidence of this can be seen in the high water absorption value of 2%.

The results of abrasion and impact resistance, and compressive strength tests were satisfactory for all the mixes except G, which failed both the impact test (by perforation of the topping) and the abrasion resistance test.

POLYMER CONCRETES WITH LOWER RESIN CONTENTS

Polymer concretes were made with 10% resin by weight using four double gap-graded mixes (B,C,I and J in Table 1) and three continuously graded aggregate mixes (K, L and M). Mix M was based on a table of ideal and quasi-ideal sand gradings published by Ehrenburg (7). This grading uses Weymouth's theory to minimise particle interference.

All seven mixes had a stiff consistency with the three continuously graded mixes having a dry sandy appearance. None of the continuously graded mixes could be screeded and floated to give a satisfactory surface finish. When viewed under a microscope (6x magnification) the surface was seen to be porous, explaining the high water absorption values. The abrasion resistance was poor (Table 4), mix K failed before the test was completed. Mixes L and M, while within the guidelines set by Sharman (13), had significantly less abrasion resistance than mixes containing 12% resin by weight.

The PC toppings made with the double gap-graded aggregate mixes proved to be far superior for trowelling and floating. After screeding, minimal effort was required to float mixes C, I and J to a pore-free surface finish. Mix B, however, proved to be too deficient in fines to achieve a good surface finish. Mix B also had less abrasion resistance and higher water absorption than C, I and J. The latter mixes had similar abrasion resistances to the 12% resin toppings.

Mix C (66% large aggregate +34% fine aggregate) appeared to be slightly easier to mix than those containing 40% fine aggregate. This mix was used to make PC toppings with a resin content of 8% by weight. The mix was dry and similar in appearance to damp sand. After screeding considerable effort was required to float to a satisfactory finish. Under the microscope the surface appeared pore-free and slightly sandy. The average abrasion rate of both the epoxy and polyester mixes was similar to the 10% and 12% mixes while the value for the initial abrasion rate was higher. This is due to loosely-bound sand being removed from the surface.

The impact resistance was determined by measuring the crater diameter after impact by a falling missile. The 12% and 10% resin mixes had high impact resistance (see Table 5), in good agreement with values reported by Sharman and Cordner (15). A decrease in impact resistance was observed for the 8% mixes - while the crater diameter did not increase the depth of penetration did. Impact testing of the 8% polyester (PE) double gap-graded and the 10% continuously graded mixes was not possible due to the topping detaching from the base slab during the test.

The results of adhesion tests are shown in Table 5. Both the polyester and epoxy 8% resin mixes had very low adhesion to the substrate. The PC toppings made with higher resin contents all had tensile adhesion strengths greater than the value of 0.7 MPa suggested by MacGregor and Sharman (11) as a minimum for export abattoir flooring. Applying a priming layer of resin to the PCC base, prior to the PC topping, resulted in satisfactory adhesion for the 8% PE mix. The priming operation raised the total quantity of resin used in this mix to nearly 9%.

COST SAVINGS

Table 6 shows a breakdown of the costs involved in producing and laying a PC floor topping in current practice. The resin accounts for approximately 50% of the total cost. By using a double gap-graded aggregate and 9-10% resin by weight, a saving of up to 25% on some commercial PC floor toppings at present in use in New Zealand could be possible. This saving in material costs may be offset to some extent by other costs. These may arise from increased aggregate costs and a requirement for labour retraining or education, and tighter specifications and quality control of ingredients and application methods. Large-scale trials will be necessary to evaluate these factors but laboratory results look promising for the large scale viability of PC toppings with reduced resin content.

ALTERNATIVE AGGREGATES

Attempts were made to locate alternative sources of quartz and quartzite aggregates which were closer to the major users. However, discussions with the New Zealand Concrete Research Association, which had conducted a survey of concrete aggregates in New Zealand (4), revealed a scarcity of such aggregates. Attention was then turned toward other aggregate types. Aggregates which have previously been used successfully to make PCC appeared to offer possibilities. Greywacke and, to a lesser extent, basalt fit this category.

Greywacke sources are widespread throughout New Zealand, and basalt is found in Northland, Auckland, Coromandel, Otago and Southland.

EXPERIMENTAL

Samples of greywacke from a local river-bed gravel pit, and basalt from an Auckland quarry were obtained. The greywacke had a reported crushing strength of 390 kN (12). The aggregates were dried for 18 hours at 105°C then sieved into fractions. Both aggregates were subangular and dark grey in color.

Trial mixtures using these aggregates produced grey to black colored polymer concretes. Black and dark colors in general are not considered desirable in a food processing environment where a hygienic appearance is required (16). Replacing the fine aggregate with white sand was not particularly effective in lightening the color. The addition of titanium dioxide pigment to a polymer concrete containing only greywacke aggregate did however produce an acceptable color. The titanium dioxide (TiO_2) was incorporated in the polymer concrete mix by one of two methods. In the first, a polyester pigment paste containing about 50% pigment by weight was mixed with the polyester resin. In the second, TiO_2 pigment was added as a powder to the aggregate which was then mixed vigorously to disperse it.

Samples of both greywacke and basalt PC tinted with TiO_2 were made with resin contents of 13% and 15% by weight using aggregate grading H in Table 1.

RESULTS

The addition of 1.4 to 3% by weight of white, TiO_2 containing, pigment paste produced-greyish colored polymer concretes similar in appearance to Portland cement concrete. The sample with 3% by weight was considered an acceptable color by the Ministry of Agriculture and Fisheries. However, by adding a small quantity of red iron oxide pigment paste to the white an acceptable coloring was produced using only 1.4% by weight of pigment paste.

The addition of TiO_2 pigment directly to the aggregate in powder form also produced acceptably colored polymer concrete. Quantities of 2 to 3% by weight were used but better dispersion techniques may result in lower levels of pigment being needed.

Table 7 shows the results of compressive strength, abrasion and water absorption tests. The results of these tests are all satisfactory. The high compressive strength values are a result of the angularity and good crushing strength of the aggregates. The workability of the mixes is not as good as that of similar graded mixes using rounded aggregates. This is to be expected as angular aggregates do not pack as densely as rounded ones.

The approximate costs for the pigment pastes and TiO_2 powder are $NZ 7/kg and $4.2/kg respectively. Thus pigmentation would add about $NZ 80 - $100/tonne of polymer concrete. This is of the same order as the cost of transporting one tonne of aggregate from Dunedin to Auckland (ie from quartzite aggregate source to the main area of use).

As sources of greywacke and basalt differ widely in characteristics such as crushing strength and density, it is recommended that tests for abrasion, impact and compressive strength should be carried out on a polymer concrete at the formulation stage when a new source of aggregate is used.

CONCLUSIONS

The results of the grading experiments show that polymer concretes can be made with resin contents of 10% and lower which have the necessary mechanical properties and workability for trowel-applied floor toppings. At these low resin levels the use of double gap-graded aggregate mixes results in superior polymer concretes to those produced with a conventional continuously graded aggregate.

The potential exists for a considerable saving (often foreign exchange) in material costs by the use of low resin-content polymer concretes. Industry must determine whether this saving in material costs outweighs any potential increases in application costs. These may arise from a requirement for labour retraining or education, and tighter specifications and quality control of ingredients and application methods. Large scale trials will be necessary to evaluate these factors, but the laboratory results look promising.

The successful use of greywacke and basalt as polymer concrete aggregates also increases the options available to manufacturers of polymer concretes. While the savings that can be made in transport costs in some centres may seem minimal, any increase in real transport costs will make these options more attractive. Furthermore a reliable local aggregate source will help prevent possible disruption to supplies. Any such source will have to be evaluated before use.

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TABLE 1--AGGREGATE GRADINGS USED FOR EXPERIMENTAL POLYMER CONCRETES

		Sieve Size μm					
		75	150	300	600	1200	2400
Cumulative Mix % Passing	A	3	13	40	40	40	100
	B	0	10	26	26	26	100
	C	0	10	34	34	34	100
	D	0	1.1	39.7	40	40	100
	E	0	0.8	29.8	48	48	100
	F	0	0	40	55	74	100
	G	0	0	12	34	62	100
	H	0	3	36	36	36	100
	I	0	2	34	34	34	100
	J	0	10	40	40	40	100
	K	0	7	21	49	75	100
	I	0	14	34	50.5	72	100
	J	0	11	25	44	68	100

TABLE 2--COMPRESSIVE STRENGTHS AND WATER ABSORPTIONS FOR 12% RESIN MIXES

MIX	RESIN		COMPRESSIVE STRENGTH	WATER ABSORPTION WEIGHT %**
	TYPE	AMOUNT	MPa *	
A	PE	12%	96	0.25
B	PE	12%	94	0.30
C	PE	12%	101	0.28
D	PE	12%	89	0.29
E	PE	12%	91 **	0.43
F	PE	12%	85	0.93
G	PE	12%	68	1.93
H	EP	12.2%	76	0.29

PE = modified polyester
EP = epoxy
* mean of 5 samples
** mean of 3 samples