Reprint

NO.57

CI/SFB (23) Yp1

UDC 692.533.15: 691.322

ALTERNATIVE AGGREGATES AND AGGREGATE GRADINGS FOR USE IN POLYMER CONCRETE FLOORS: ECONOMICS AND PERFORMANCE

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Reprinted from ***BUILDING MATERIALS DURABILITY IN THE FOOD INDUSTRY,*** Technical Paper P44, Building Research Association of New Zealand (1985)

BUILDING RESEARCH ASSOCIATION OF NEW ZEALAND BRANZ

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ABSTRACT

Polymer concretes are used extensively by the food industry in New Zealand as floor toppings in processing plants. They perform well in a variety of environments but are characterised by much higher material costs than Portland cement concrete. The bulk of this cost is the resin. Research into alternative aggregate gradings was carried out to determine whether the use of such gradings could enable a reduction in the resin content of polymer concrete (PC) floor toppings. Gap-grading proved to be effective in achieving this aim.

Experimental mixes using gap-gradings and with greywacke substituted for quartzite were subjected to mechanical tests for compressive strength, and abrasion and impact resistance, to estimate their probable in-service performance.

KEYWORDS

Abrasion; Aggregates; Alternatives; BRANZ; Concrete; Costs; Epoxy; Freezing works; Flooring; Food processing; Gap-grading; Grading; Greywacke; Resin; Polyester; Polymer concrete, Water absorption; Workability.

INTRODUCTION

Floors in many food processing plants are exposed to harsh environments in which they are expected to withstand mechanical wear-and-tear and to resist chemically corrosive liquids. In New Zealand this is a particular problem for the meat and dairy industries.

Mechanical wear-and-tear results from 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 from corrosive wastes and by-products such as lactic acid in milk (Sharman 1983). Concrete has a record of poor performance under such conditions as it is attacked by acids and most food wastes are acidic. 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.

Polymer concrete is a material in which the Portland cement and water binding phase of ordinary concrete has been totally replaced by a resin such as a polyester or epoxy. Unpolymerised resin is mixed with a catalyst then added to aggregate. The resin polymerises and reaches a hard cure in one to two hours. Full strength is reached in seven to fourteen days. The cured resin with a suitable aggregate has considerably better compressive strength, tensile strength, abrasion, impact and corrosion resistance, than Portland cement concrete. The main drawback with polymer concrete systems is their cost, an extra \$30-\$50/m^2 on top of that of the basic concrete floor. This study 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 polymer concrete samples carried out between 1981 and 1983 by pyrolysis at 550 ^{o}C, showed that the resin content usually ranged from 15 to 20% by weight (MacGregor and Sharman 1983). 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 882:1965. This grading type has been successfully used to make Portland cement concrete for many years. In theory a continuously graded aggregate gives the best (densest) packing. However, this packing can only be achieved if the aggregate is placed in layers by hand. In practice, the geometry is limited by the fact that the entrance to voids between the large aggregate particles is smaller than the size of the voids themselves (Li and Stewart, 1973), as can be seen in Figure 1. The use of fine aggregate fractions smaller in diameter than the void entrance gives better packing and workability as they can move freely between the large particles into voids. The term 'gap-graded' is used to described any aggregate or mix of aggregates which, when sieved as described in NZS 3111: 1980, is missing any intermediate aggregate fraction. Several workers (Li and Ramakrishnan, 1973; Ehrenburg, 1980) have reported that Portland cement concretes made with gap-graded and, more especially, double gap-graded aggregates have better workability than mixes having the same water and cement contents but continuously graded aggregates.

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 modified 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; and -0.15 to +0.075mm. The +2.4 and -0.075mm fractions were 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. Cylindrical moulds 60mm high and 30mm in diameter were filled for compressive strength tests (see MacGregor and Sharman 1983). The cylinders were demoulded after one day and cured for a total of 14 days at 20 °C and 65% relative humidity. Compressive strength tests were carried out using a Dartec M1000 RE universal testing machine with a crosshead speed of 1mm/min. Abrasion resistance was measured as described by Sharman (1982). Absorption tests were carried out as described in ASTM C413-1980 except that the moulds were 27mm high and had a 27mm diameter. Impact testing was carried out as described by Sharman and Cordner (1979).

RESULTS AND DISCUSSION

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.

The double gap-graded mixtures proved to be slightly easier to mix than the single and non-gap-graded mixes. Grading B made the most resin-rich mix, but a result of the decreased quantity of fine aggregate compared to grading A was an increased difficulty in achieving a satisfactory surface finish. All the mixes except G had resin-rich non-porous surfaces and performed satisfactorily in mechanical tests. Mix G proved impossible to trowel and resulted in a porous mass. Evidence of high porosity can be seen in the very high water absorption value of 2%, and is attributed to a shortage of fines.

10% Resin

Three double gap-graded and three continuously graded mixes were used in attempts to make 10% resin by weight PC. The double gap-graded mixes were B, C and H in Table 1 and the continuous graded mixes I,J and K.

All six mixes were dry in appearance and similar in consistency. None of the continuously graded polymer concretes could be screeded and floated to give a good surface finish. When viewed through a microscope at a magnification of x6, the surface was seen to contain pores, explaining the high water absorption values. A sealing coat of resin would be essential to produce a satisfactory surface.

When tested for abrasion resistance mix I failed before the test was completed. Mix J, while within the guidelines set by Sharman (1982), had less abrasion resistance than the double gap-graded mixes. This contrasts with the double gap-graded mixing, which proved to be far superior when it came to screeding and floating. Both gradings C and H produced a polymer concrete with a good pore-free surface. Mix B, however, proved to be too deficient in fine aggregate to achieve a good surface finish. The abrasion resistance of the double gap-graded mixes was high (see Table 4) although slightly less than the 12% mixes.

8% Resin

Mix C was repeated using 8% resin by weight. At this resin content the polymer concrete appeared very dry. After screeding, the mix required some effort to float to a reasonable finish. The surface appeared pore free under microscopic examination and slightly sandy. The initial abrasion values for the 8% resin polymer concretes are higher than corresponding mixes with 10% and 12% resin, although the average wear rates are satisfactory. The high initial rate is a result of loosely bound particles of sand being removed from the surface.

The impact resistance of 12% resin mixes was high for both epoxy and polyester polymer concretes and in good agreement with values reported by Sharman and Cordner (1979). A decrease in impact resistance was observed as the resin content decreased. At 8% resin by weight some penetration through the topping to the concrete bases was observed, although this depended on the topping thickness. Impact testing at this resin level was complicated by delamination of the PC topping from the unprimed concrete base. The use of a priming resin layer before the application of the PC topping and the subsequent use of a sealing coat would result in better impact resistance.

COST SAVINGS

Table 6 shows a breakdown of the costs involved in producing and laying a PC floor topping. The resin accounts for approximately 50% of the total cost. A double gap-graded polymer concrete with 10% resin content can result in a saving of up to 25% over a conventional polymer concrete. This saving in material costs may be offset to some extent by an increase in other 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.

ALTERNATIVE AGGREGATES

Discussions with the New Zealand Concrete Research Association, which had conducted a survey of concrete aggregates in New Zealand (de Bock 1981), revealed a scarcity of alternative supplies of quartzite aggregates. However, Portland cement concrete has been made very successfully for many years using aggregates such as greywacke. Greywacke sources are widespread throughout New Zealand.

Experimental

Samples of greywacke from the Otaki river were obtained and dried for 18 hours at 105 °C then sieved into fractions. The aggregate was sub-angular and had a reported crushing strength of 390 kN (New Zealand Concrete Research Association 1982).

Trial mixtures using this aggregate produced polymer concretes which had a very dark grey to black colour. Black and dark colours in general are not considered desirable in a food processing environment where a hygienic appearance is required (Sharman and Cordner 1980). Replacing the fine aggregate with white silica sand was not particularly effective in lightening the colour. However, the addition of titanium dioxide (TiO_2) pigment to a polymer concrete containing only greywacke aggregate produced an acceptable colour. The titanium dioxide 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 were made with resin contents of 13% and 15% by weight using aggregate grading H in Table 1.

Results

The addition of 1.5 to 3% by weight of white TiO_2 pigment paste produced greyish-coloured polymer concretes similar in appearance to Portland cement concrete. The sample with 3% by weight was considered an acceptable colour by the Ministry of Agriculture and Fisheries. However, by adding a small quantity of red iron oxide pigment paste to the white an acceptable colouring was produced using only 1.4% by weight pigment paste. The addition of TiO_2 pigment directly to the aggregate in powder form also produced acceptably coloured polymer concrete. Two to three per cent by weight was used but better dispersion techniques than those used in the present study may result in lower levels of pigment being needed.

Table 5 shows the result 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 not unexpected, since angular aggregates do not pack as densely as rounded ones.

The approximate costs for the pigment pastes and TiO_2 powder are \$7/kg and \$4.2/kg respectively. Thus pigmentation will cost about \$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.

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 use as floor toppings in food processing plants. 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 in material costs (often in foreign exchange) by the use of low resin polymer concretes with 10% or less resin by weight. Manufacturers must determine whether any saving in material costs made by reducing resin content outweighs any potential increases in application costs.

The successful use of greywacke as a polymer concrete aggregate 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 this option more attractive. Furthermore, a reliable local aggregate source will help prevent possible disruption to supplies. As sources of greywacke 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.

REFERENCES

American Society for Testing and Materials. 1980. Standard test method for absorption of chemical-resistant mortars, grouts, and monolithic coatings, ASTM C413. Philadelphia.

British Standards Institution. 1965. Specification for aggregates from natural sources for concrete. BS 882. London.

de Bock, J.F. 1981. Testing of New Zealand aggregates. New Zealand Concrete Research

Association. Porirua.

Ehrenburg, D.O. 1980. An analytical approach to gap-graded concrete. Cement, Concrete, and Aggregates 2 (1) 39-42.

Li, S. and Ramakrishnan, V. 1973. Gap-graded aggregates for high-strength quality concrete. Highway Research Board Highway Research Record 441. Washington, D.C.

Li, S. and Stewart D.A. 1973. Compatible gradation of aggregates and optimum void-filling concrete proportioning for full consolidation. Highway Research Board Highway Research Record 441. Washington, D.C.

MacGregor, I.D. and Sharman, W.R. 1983. Quality control of polymer mortar flooring surfacings - resin content and aggregate grading by pyrolysis. Building Research Association of New Zealand Conference Paper 3. Judgeford.

New Zealand Concrete Research Association. 1982. Concrete aggregates. Information Bulletin IB015. Porirua.

Sharman, W.R. 1982. Abrasion resistance of freezing works flooring materials. Building Research Association of New Zealand Research Report R36. Judgeford.

Sharman, W.R. 1983. Food processing floors: a guide to design, materials and construction. Building Research Association of New Zealand Technical Paper P36. Judgeford.

Sharman, W.R. and Cordner, R.J. 1979. Impact resistance of freezing works flooring materials. Building Research Association of New Zealand Research Report R30. Judgeford.

Sharman, W.R. and Cordner, R.J. 1980. Freezing works flooring materials: A selection guide for corrosion resistance. Building Research Association of New Zealand, Technical Paper P27. Judgeford.

Standards Association of New Zealand. 1980. Specification for methods of test for water and aggregate for concrete. NZS 3111.

ACKNOWLEDGEMENTS

The assistance of B. Vautier and M. McCartain in carrying out tests is gratefully acknowledged. The New Zealand Concrete Research Association is also thanked for information on aggregate types and sources and for loan of equipment.

The following companies (in alphabetical order) are thanked for the supply of resins, aggregates, pigments and information:
A.C. Hatrick, AHI - N.Z. Fibreglass, Chemby Marketing, Ciba Geigy N.Z. Ltd., Mintech N.Z. Ltd., Oregon Paints N.Z. Ltd., Revertex Industries N.Z. Ltd., Tergo Industries Ltd.

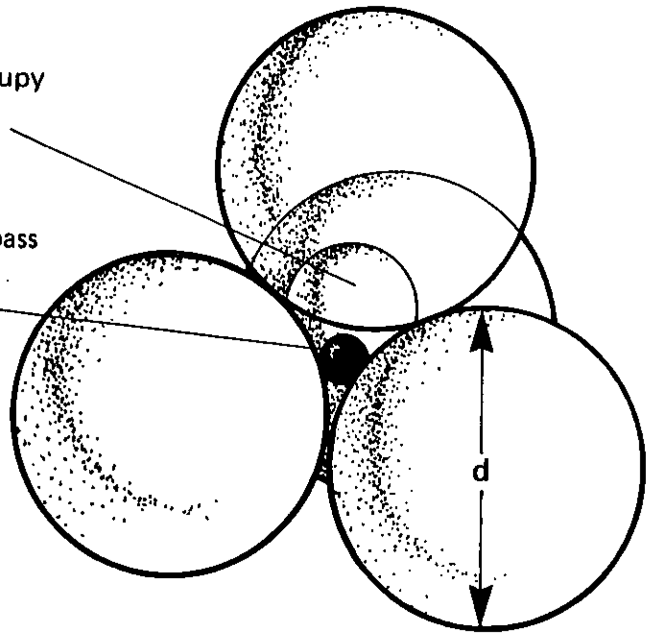

Figure 1. **Void in close packed spheres showing void occupation and void entrance sizes**

Table I Aggregate Gradings used for Experimental Polymer Concretes

		Sieve Size					
	Mix	75μm	150μm	300μm	600μm	1.2mm	2.4mm
Cumulative % 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	39.1	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	7	21	49	75	100
	J	0	14	34	50.5	72	100
	K	0	11	25	44	68	100

Table 2 Compressive Strengths and Water Absorptions for 12% Resin Mixes

Aggregate Grading	Resin Type	Mean Compressive Strength MPa	Mean Water Absorbtion weight %
A	PE	96	0.2 *
B	PE	94	0.22 *
C	PE	101	0.18 *
D	PE	89	0.24 *
E	PE	91	0.43
F	PE	85	0.93
G	PE	67	1.93
H	EP	77	0.29

PE = modified polyester

EP = epoxy

* = one value only

Table 3 Results of Selected Abrasion Resistance Tests on 12% Resin Mixes

Aggregate Grading	Resin	Average Abrasion Rate $mm^3/1000$ secs	Initial Abrasion Rate $mm^3/1000$ secs
A	PE	0.3	1130
A	PE	4.7	947
C	PE	2.3	1192
C	PE	0.3	1130
C	EP	2.3	322
C	EP	1.0	850

Table 4 Test Results for 10% and 8% Resin Polymer Concretes

Aggregate Mix Grading	Resin Type	Resin Content % weight	Compressive Strength MPa	Abrasion mm³/1000s Average	Abrasion mm³/1000s Initial	Water Absorption weight %
B	PE	10	100	10.2	582	0.85
C	PE	10	101	5.7	1147	0.3
H	PE	10	97	4.4	1147	0.75
K	PE	10	93	14.5	2438	1.8
C	EP	10	81	1.6	1242	0.2
C	EP	8	73	2.4	1605	0.55
C	PE	8	84	3.7	1762	1.1

Table 5 Test Results For Greywacke Polymer Concrete

Resin Content %	Resin Type %	Pigment Paste %	Pigment Powder %	Compressive Strength MPa	Abrasion Average mm³/1000s	Resistance Initial mm³/1000s	Water absorption % By Weight
15	PE	1.5		113	5.5	1282	0.35
13	PE	1.4		113	5.3	1790	0.38
13	EP		3.0	77	3.2	1134	0.24

Table 6 Cost Analysis of Polymer Concrete Flooring *

Component	Contribution to Total Cost
Surface preparation	10%
Aggregate	16%
Laying	22%
Resin & Hardener	52%
	100%

* data averaged from information supplied by commercial floor layers.

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ISSN 0111–7459