STABILISATION OF EARTH ROADS WITH WATER-BASED POLYMER EMULSIONS

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Abstract

Laboratory results show that by optimising the polymer type and stabiliser system, emulsions can be produced which, when diluted with water and mixed into sands or soils with a high clay content, can produce thick aggregates with high load bearing and water holdout characteristics. Unconfined compressive strength (UCS) and water uptake results on cores before and after soaking in water are given for a wide range of soil types and levels of polymer. The minimum requirement of 0,75 MPa for a C4 pavement is exceeded with only 0,25% of emulsion on soil. Practical results with surface applications only and incorporation to depth on several roads, a parking lot and the entrance to a sugar mill are reported.

Introduction

In southern Africa, finance for maintenance and construction of roads is scarce. The CSIR (Jones, 1996) have indicated that for gravel roads in townships a surface only treatment costing less than R2/m^2 and remaining completely effective for one, but preferably two, years is required. For roads carrying heavier loads, the traditional method of importing aggregate is becoming prohibitive because of the scarcity of suitable material and the high cost of transporting aggregates over long distances. Polymer (plastic) emulsions are used extensively to form thin layers of less than 3 mm, in paints and waterproofing screeds on walls and roofs. Their excellent resistance to embrittlement, UV light and acid rain, and their good adhesive properties, made them suitable for blending at low levels into bitumen, tar and cement to upgrade these materials. This paper describes how polymer emulsions were modified to give thick consolidated layers with high load bearing strengths and good resistance to wear by water and traffic. Also discussed are the best techniques of mixing, drying and compacting the soils to give optimum results in laboratory tests and the performances of several polymer treated roads after extended periods of trafficking.

Procedures

Experiment 1

In 1983 the Transvaal Provincial Administration (Zadzick, 1983) carried out a practical road trial in which a diluted polymer emulsion was applied at the low rate of 0,06 L/m^2 to the surface of a recently completed gravel road. The origin of this emulsion was from earlier laboratory work which showed that the type and level of stabiliser that was used during polymerisation, determined whether the emulsion would form thick load bearing slabs, or thin surface skins with underlying loose sand, when poured onto the surface of sand and allowed to dry (Bishop, 1978). Those polymer emulsions stabilised with the lowest levels of high surface tension stabilisers produced the strongest sand aggregates. For the emulsion used in Experiment 1 the polymerisation was carried out with the lowest level of polyvinyl alcohol stabiliser necessary to prevent the polyvinyl acetate emulsion from coagulating on storage. The minimum film forming temperature (mft) of the polymer was reduced to 12°C with an external plasticiser to ensure film formation in most climatic conditions in southern Africa. This emulsion at 58% solids content was diluted 50 times with water in a spray tanker and then applied evenly over the surface of a road near Pretoria, at the rate of 0,06 L in 3 L/m^2 of water. The gravel of the road contained clay, with a plastic index (PI) of approximately 10, and the application was made in May, at the start of the dry winter months. The condition of the road was compared regularly with two adjacent sections which had received no aggregating agent. The results after four months of trafficking are given in Table 1.

Experiment 2

To improve the resistance to water of the PVAc homopolymer a number of colloid stabilised copolymer emulsions were formulated with the following monomer combinations: vinyl acetate-acrylic, styrene-acrylic, veova-acrylic and acrylic-acrylic. These emulsions were compared to cement, hydrated lime and a bitumen emulsion as soil bonding agents in a clay containing soil (PI=16). The unconfined compressive strength (UCS) was the preferred Civil Engineering test, as it compares load bearing performances in both the dry state and after submersion in water for four hours. These results are also applicable for other load bearing applications such as earth bricks. For an aggregate to conform to the requirements for the base of a C4 pavement it must achieve a UCS of 0,75 MPa. For the true potential of the polymer emulsions to be realised in laboratory tests it was found that the following mixing and drying procedures had to be closely followed. After determining the optimum moisture content (OMC) of the particular soil, the polymer emulsion at 1% active on aggregate, was pre-blended with 33% more water than was needed to achieve OMC. This blend was then mixed thoroughly with a fresh sample of soil. The damp mixture was then spread out in a layer ±50 mm thick and left in a shaded area (±23°C and 55% relative humidity) for 48 hours. It was then compacted into the moulds. The moulds were split and the free standing cores were dried at ambient temperatures for 24 hours, and then at 60°C in a forced draft oven for 72 hours. Finally, the dry soil cores were weighed before one was crushed dry and the other duplicate was submerged in water for four hours. After removing and dabbing off the excess water the core was re-weighed and crushed immediately. The extent to which water had penetrated into the core was visually assessed. The results from other experiments using cores bound with 4% cement, hydrated lime and a bitumen emulsion, dried in the ways recommended, are included for comparison. The results are given in Table 2.

Experiment 3

Using the same test procedure as in Experiment 2, decreasing levels of the best styrene-acrylic copolymer (B) in Table 2 were mixed into a high clay containing soil (PI=31) and a sand (PI=2) to determine the levels at which it ceased to have any visual bonding effects. The criteria for assessment after the four hour soak were the ability of the cores to (i) be removed and have a UCS measurement conducted on them, (ii) prevent the ingress of water, (iii) remain dimensionally stable without swelling or collapsing and (iv) be sufficiently bound so as to prevent clay particles from being permanently suspended in the supernatant liquid after physically stirring the collapsed cores for 20 revolutions with a palette-knife. Cores bound with 4% cement and hydrated lime were included for comparison. The results are given in Table 3.

Experiment 4

In 1989, a road was built in a red sand (PI=3) using the styrene-acrylic copolymer (A) at Sodwana Bay, KwaZulu-Natal. The area was 100 x 10 m and the copolymer was incorporated to 150 mm. To ensure drying in a reasonable time in the very humid environment, dry cement at 1% (assuming that 1 m^2 x 0,15 m of sand weighs 270 kg) was premixed into the 150 mm layer. The styrene-acrylic emulsion with a solids content of 50% was diluted 1:1 with water and was applied by a water tanker evenly over the test area at a rate of 2,4 L/m^2. A grader thoroughly mixed the 150 mm layer before the road was shaped and compacted with a pneumatic roller. The dry copolymer content on sand was 0,22%. After four months of trafficking the load bearing strengths were measured in the 0 to 150 mm and the 150 to 300 mm layers (Table 4). The road was also visually assessed on an annual basis (Brotherton, 1997).

Table 1. Condition of road four months after treatment in Experiment 1.

Treatment	Loose material	Potholes	Corrugations	Cracks	Deformations	Dust	Stoniness
No treatment	Considerable	Many; depth ±3 cm	Slight	Ruts	None	Very level 5	Considerable, many protruding stones
PVAc Polymer onto surface at 0,042 kg dry/m^2	Slight	None	None	None	Considerable	Rather level 3	Slight, few protruding stones
		Moisture (%)			Relative density (%)		
		87.03.30	87.05.19	87.05.19	87.03.30	87.05.19	87.05.19
No treatment Depth 150 mm Depth 300 mm		11,4 18,8	11,3 18,3	7,8 8,2	97,4 87,5	96,9 87,1	90,8 89,1
Polymer onto surface at 0,042 kg dry/m^2 Depth 150 mm Depth 300 mm		17,1 18,8	16,9 18,5	9,2 9,2	92,2 88,8	92,1 89,0	97,4 93,1

Table 2. Unconfined Compressive Strengths and water uptakes in Experiment 2 (means of duplicates) at 1% dry polymer on soil.

Polymer type	Unconfined compressive strengths (MPa)		Water Uptake %
	Dry	After submersion	
PVAc homopolymer	1,9	0,1	15,1
VA-acrylic copolymer	1,4	0,2	Collapsed
Veova- acrylic copolymer	1,8	0,6	6,7
Styrene-acrylic copolymer (A)	1,6	0,6	5,2
Styrene-acrylic copolymer (B)	2,8	0,9	5,8
Acrylic-acrylic copolymer	2,9	0,9	5,6
Cement at 4%	1,2	1,1	13,8
Hydrated lime at 4%	1,2	0,3	12,3
Bitumen emulsion at 4% (cationic)	0,6	0	6,4

Table 3. Water resistance of sand and soil cores in Experiment 3.

Level of dry copolymer (% on gravel)	Sand (PI = 1)					Soil (PI = 16)				
	UCS (MPa)		Water uptake (%)	Core stability	Clay dispersion	UCS (MPa)		Water uptake (%)	Core stability	Clay dispersion
	Dry	Wet				Dry	Wet			
4,0000	11,9	3,3	0,6	Excellent	NA	19,1	8,2	1,6	Excellent	NA
1,0000	2,8	1,1	1,1	Excellent	NA	3,6	0,9	2,6	Excellent	NA
0,5000	1,9	0,7	1,4	Excellent	NA	3,1	0,3	4,2	Excellent	Nil
0,2000	0,9	0,3	2,1	Excellent	Nil	3,0	0,1	16,1	Excellent	Nil
0,0200	0,2	Collapsed	–	Collapsed	Nil	2,8	Collapsed	–	Collapsed	Nil
0,0020	0,1	Collapsed	–	Collapsed	Nil	2,4	Collapsed	–	Collapsed	Nil
0,0002	0,1	Collapsed	–	Collapsed	Severe	2,4	Collapsed	–	Collapsed	Severe
Nil	0,1	Collapsed	–	Collapsed	Severe	2,4	Collapsed	–	Collapsed	Severe

Table 4. Test results on road four months after treatment in Experiment 4.

Treatments	Depth (mm)		
	0 – 150	151 – 300	301 – 450
0. No aggregating agents			
b UCS	402	152	181
CBR	42	14	17
Average penetration	6,0	13,9	12,2
A. 0,0% Cement + 0,4% REV 6 (wet) into top 150 mm			
UCS	1 035	977	167
CBS	123	115	18
Average penetration	2,6	2,7	13,3

Experiments 5 and 6

For tests on roads composed of clay containing soils the best water resistant acrylic-acrylic and styrene-acrylic (B) copolymer emulsions in Table 2 were used to construct, firstly, a parking lot at Mariannridge, KwaZulu-Natal, and, secondly, a road in Maputo, Mozambique, in September 1996 and February 1997 respectively. In the former trial 0,21% dry copolymer was incorporated into 150 mm of decomposing granite (PI=10) and at the latter site 0,5% dry copolymer was mixed into the top 50 mm of a highly erodible red soil (PI=16%). The first trial received no additional wearing surface, whereas in the second trial 3 x 200 m lengths of road received (i) no additional treatment, (ii) a low cost bitumen prime and (iii) the bitumen prime followed by a hot chip and spray. The state of roads after 18 and 12 months trafficking are discussed in Results 5 and 6 respectively.

Experiments 7 to 18

Surface only applications of 0,25 L/m^2 of the styrene-acrylic copolymer emulsion (B) in 3,3 L/m^2 of water were applied evenly over 200 x 8 m sections of 12 different Gauteng gravel roads in August 1997 by the CSIR (Jones, 1997). The roads were bladed just prior to the copolymer applications. The trial sections were compared regularly against the adjacent control sections of road for dust suppression, riding quality and gravel loss. The results after four months are given in Table 4 and Figure 1.

Experiment 19

The entrance to Darnall sugar mill is subjected to a high intensity of very heavily loaded vehicles. It is very dusty when dry and deforms badly under load in the wet. The material was a mixture of oversize (80 mm) rocks and a clay containing soil (PI=16). UCS tests on the natural soil alone and with 1,0% dry of the styrene acrylic (B) gave the following results:

Test	Polymer level (% dry on soil)	
	0	1
UCS (MPa)		
Dry	0,94	1,96
Wet	Collapsed	0,33
Water uptake (%)	–	5,4%

A trial section of 110 x 10 m was scarified to 100 mm on November 4, 1997. A quantity of 0,8 L/m^2 of the styrene acrylic copolymer (B) emulsion was diluted with 16 L/m^2 of water, and 12 L/m^2 of this was incorporated by blading into the 100 mm layer. After shaping and compacting with a 10 ton vibrating roller, the remaining 4 L/m^2 of diluted polymer was applied over the area in several passes to achieve flooding and to ensure a polymer rich surface layer on drying. The condition of the test site on February 26, 1998 is illustrated in Figure 2. On March 4, 1998, four months after the original treatment, the remaining 4 000 m^2 of the entrance area was treated as above. Five days later the entire area received a spray of a solvent-based bitumen prime (RTH/14), followed by two sprays of hot bitumen (150 to 200 PEN), the first of which was overlaid with stone chips of 19 mm and the second with stone chips of 9,5 mm (Figure 3).

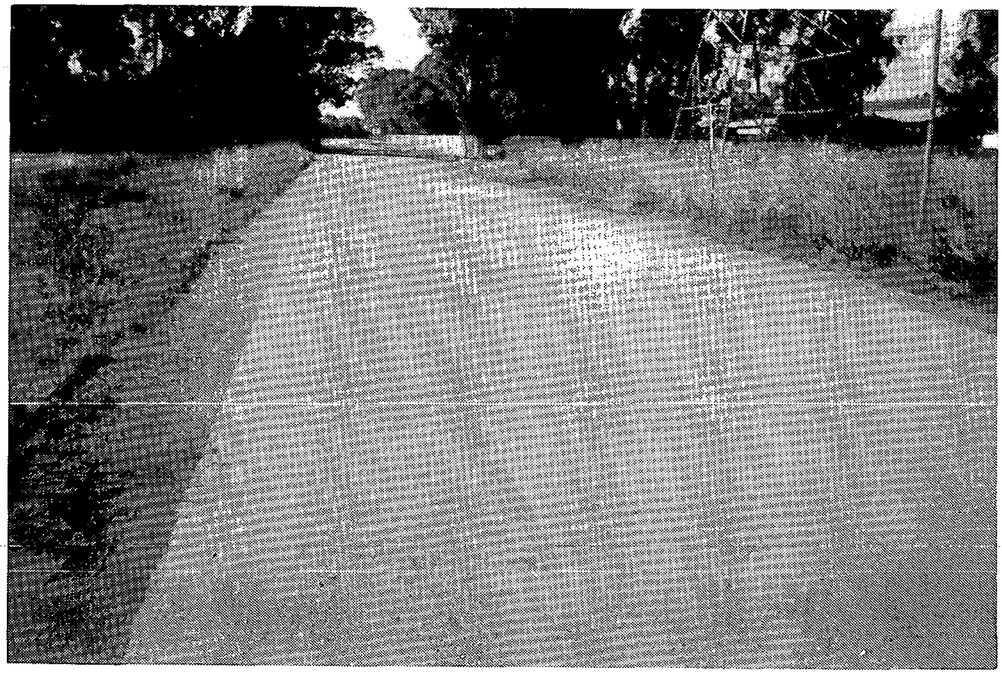

Figure 1. Surface only treated road in Experiment 13 after four months.

Table 5. Condition of roads in Experiments 7 to 18 after four months.

Experiment No.	Road No.	Material	PI	Performance	Comment
7	1833	Ferricrete	Low	Poor	Ravelling / corrugations
8	2388	Sandstone	High	Good	–
9	1814	Ferricrete	High	Fair	Ravelling / erosion
10	45	Sandstone	Low	Good	Poor drainage / potholing
11	964	Shale	Low	Poor	Material breakdown
12	2760	Shale	High	Poor	Material breakdown
13	2383	Chert	High	Good	–
14	2540	Chert	Low	Poor	Ravelling / corrugations
15	101	Granite	Low	Poor	Ravelling / corrugations
16	1410	Granite	Low	Fair	Ravelling / corrugations
17	67	Dolerite	Low	Poor	Ravelling / corrugations
18	1313	Andesite	High	Good	Ravelling / corrugations

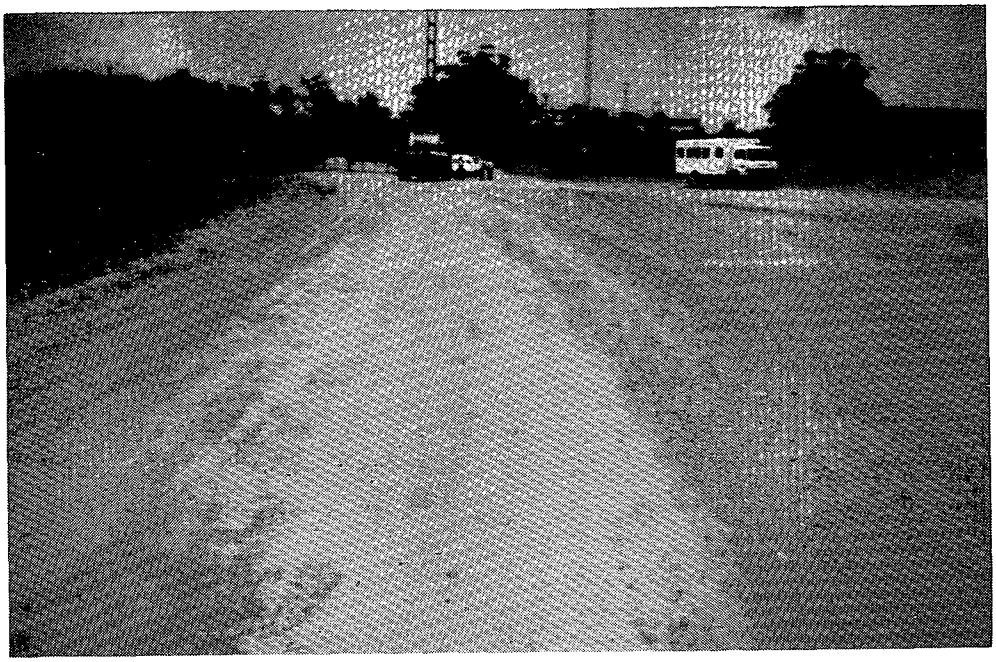

Figure 2. Treated section of mill entrance in Experiment 19 after four months.

Figure 3. Application of bitumen chip and spray over polymer stabilised base in Experiment 19.

Results

Experiment 1

Four months after treatment, the section of road that received the surface-only application of 0,042 kg/m^2 of the dry PVAc homopolymer showed markedly improved resistance to traffic in comparison with the adjacent control sections. The increasing densities of the soil at 150 mm, and even 300 mm, below the surface skin of homopolymer, which could not have penetrated more than about 5 mm, are noted (Table 1). With the advent of the spring rains the beneficial effects became less obvious (not reported here).

Experiment 2

Table 2 shows the styrene-acrylic (B) and the acrylic-acrylic copolymer emulsions to impart substantially better water resistance to the soil cores than does the PVAc homopolymer. The noted fall-off in load bearing strengths that is evident after soaking is reversed after about two hours of air drying (not reported here) and should not be a problem on well cambered roads.

Experiment 3

The higher clay-containing soil requires more copolymer to achieve the same degree of waterproofing and wet load bearing strength than does the sand (Table 3). This is despite its inherently higher dry load bearing strength. At 1,0% dry copolymer (B) on soil the clay-containing core has good water holdout properties and the UCS at 0,90 MPa after soaking just satisfies the 0,75 MPa requirement for a C4 pavement. At 0,2% copolymer the soil core still imparts sufficient bonding to the soil particles to overcome the swelling forces of the clay components. At 0,002% the soil core collapses, but a reduction of dispersed clay in the supernatant water after stirring is noted. At lower copolymer addition levels no visible differences between treated and control cores were noted.

Experiment 4

Tests on the sand road showed that incorporation of 0,9% cement and 0,22% dry copolymer into the top 150 mm resulted in substantial increases in the load bearing strengths in the 0-150 and 150-300 mm layers after four months of trafficking, compared with adjacent sections of control road. See UCS, CBR (California Bearing Ratio) and dynamic cone penetrometer results in Table 4. Three years after treatment the road, which was still in good condition apart from some small potholes which resisted further erosion, was overcoated with a hot bitumen chip and spray (Brotherton, 1997).

Experiments 5 and 6

After 18 months of use the parking lot described in Experiment 5 had a surface which was free of distortions, despite the trafficking and the more than 1 500 mm of rainfall to which it had been subjected. Some runner grass which had established itself in the expansion cracks that had initially formed, had not damaged the surface. Mole activity, which was prevalent on all sides of the acrylic-acrylic copolymer consolidated area, was completely absent in the test strip.

In Experiment 6, all of the treated 3 x 200 m copolymer containing sections were in good condition after 12 months. The 200 m section without an extra wearing surface showed the familiar distortion free surface of previous copolymer (B) roads and was in contrast to the badly rutted and rock-strewn condition of the adjacent control sections after only four months of trafficking.

Experiments 7 to 18

The four roads that had hard, compacted surfaces at the time of spraying the copolymer (B) emulsion six months previously, had excellent surfaces despite having been subjected to trafficking and over 100 mm of rain. In addition to maintaining an acceptable riding quality and reducing gravel loss in dry conditions, the copolymer treatment was also observed to reduce slipperiness in wet conditions (Jones, 1997). On the sections of those roads where the grader had deposited thick layers (more than 10 mm) of loose material, prior to spraying, the binding performance was significantly reduced.

Experiment 19

The good resistance to distortion of the layer of copolymer (B), soil and rocks after four months of excessively heavy trafficking and summer rain is illustrated in Figure 2. Two months after the surface layer of bitumen and stone chips had been added for improved wear and water resistance, the complete treatment was still in excellent condition (Figure 4).

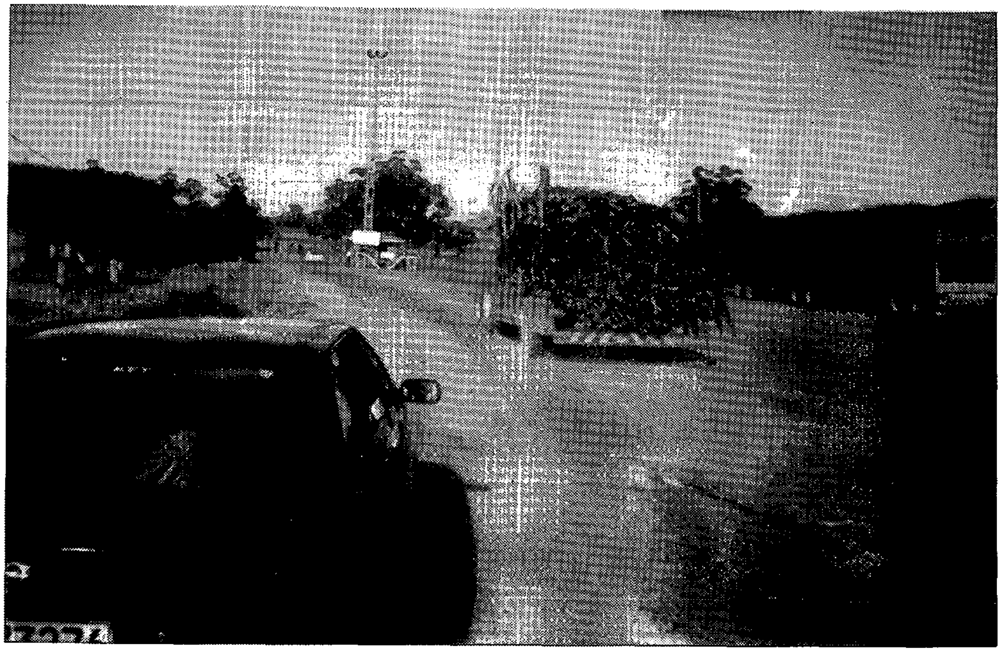

Figure 4. Condition of entrance to mill two months after applying the bitumen wearing surface in Experiment 19.

Discussion and recommendations

For surface applications of the styrene-acrylic (B) copolymer to produce all-weather skins on gravel roads which reduce dust generation in dry conditions and skidding in wet conditions, the initial road surface must be firm. Roads with loose, powdery surfaces must have water applied to them to achieve the OMC. After mixing in, shaping and compacting the road should be left for 24 hours before applying the emulsion at 0,2 L/m^2 in 3 L/m^2 of water to give complete coverage. For newly constructed gravel roads the copolymer treatment should be applied within a few days of completion to prevent ravelling. The road can be trafficked while applying the copolymer, but it is advisable to divert traffic until the wet, white coating has dried to a colourless film (approximately two hours).

The incorporation technique of the styrene-acrylic (B) and acrylic-acrylic copolymers shown in Table 2 results in thick layers with excellent load bearing and water resisting properties. The magnitude of these properties is directly related to the level of copolymer applied. To this end, the use of thinner, more polymer rich layers (or the presence of the right proportion of coarse material) will result in more effective aggregates. The procedure of retaining approximately 25% of the copolymer for a surface application, as in Experiment 19, also ensures a more polymer rich layer on the surface. In soils with medium to high clay contents high rates (approximately 16 L/m^2) of dilution water are required for good distribution of the copolymer through 75 mm, whereas in sands the requirements are much lower (2 L/m^2). The cost of the copolymer emulsion at 0,8 L/m^2 is competitive with the cost of importing gravel. The superior properties of water holdout and increased load bearing imparted by the copolymer should justify its use at higher rates.

Conclusions

The styrene-acrylic (B) and acrylic-acrylic emulsions tested form aggregates that have excellent load bearing strengths, waterproofing and wear resisting properties with a wide range of soil and sand types. Polymer emulsion chemistry is an exact science which can be accurately manipulated to give an end product with the desired properties. Further research into road building applications will undoubtedly improve the efficiencies of the above copolymers and make them even more competitive against the traditional, high volume/lower priced materials that have traditionally been used for building roads.

The low weights of copolymer emulsion required, coupled with the fact that the only other materials necessary to create load bearing aggregates are *in situ* soil and water, means transport costs to the building site are low. Other advantages are ease of application without sophisticated equipment and the ability to wash off fresh spills with water, indicating that such copolymers can play a vital role in providing roads and houses in third world countries.

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