NOVEL REINFORCED ACRYLIC EMULSION BASED ROOF WATERPROOFING SYSTEMS

M. S. SMIT

National Building Research Institute
Pretoria, South Africa

SUMMARY

This paper discusses a novel roof waterproofing system consisting of specially formulated acrylic based emulsions reinforced with non-woven fabric. The system is applied on roof decks by embedding a non-woven fabric in, and saturating it with, an emulsion. When this dries, additional emulsion is applied as a top coat. This system gives a continuously bonded, seamless waterproof membrane. The properties and the recommended minimum requirements of the system are discussed.

The poor performance of certain traditional roofing materials, such as paper-based bituminous felts [1, 2] when faced with the demands of modern architectural design, coupled with recent developments in the fields of elastomeric and plastomeric materials have led to the appearance of new waterproofing systems.

In South Africa the formulation of a reinforced acrylic emulsion roof waterproofing system is a good example of such a development. The non-woven reinforcing materials used in the system initially were developed in the textile industry[3] and have been successfully applied in geotechnical engineering.[4] Acrylic emulsions have been used successfully as paint binders.[5] They have been continuously improved and now are also being used for roof waterproofing.[6] Combining these two materials provides a waterproofing system that offers a solution to some problems encountered with more traditional roofing approaches.[7]

The system is applied by embedding a non-woven fabric in, and saturating it with, an emulsion applied in situ to a roof screed. When this dries additional emulsion is applied as a top coat to produce a continuously bonded, seamless waterproofing membrane.

An investigation of the performance of a non-woven fabric in association with five different acrylic based emulsions is reported in this paper. The properties of the five systems are compared with those of bituminous felt systems.

The demands on a roofing material vary from country to country,[8] and no single property[9] may be used as a criterion of acceptance. Therefore, to characterize this waterproofing system the following properties were considered[10]:

- tensile strength;
- tear strength;
- elongation at break;
- impact resistance;
- fatigue resistance;
- permeability;
- weathering and maintenance.

EXPERIMENTAL DETAILS

Five different, commercially available acrylic emulsions specially formulated for the purpose were used in the investigation. Their properties are listed in Table 1.

Because the rheology of the emulsions was regarded as important to film formation and good flow, the viscosities of the materials were determined at 10C (50F) and at 25C (77F), which represent typical winter and summer average ambient temperatures. The results are presented in Figure 1.

A polyester fibre, non-woven fabric, mechanically bonded from continuous fibres with an average diameter of 25 to 30μm (1 to 1.2 mils) and having a mass of 150 ± 5 grams per square meter (5.3 ± 0.2 oz/ft^2) was selected for use as reinforcement. This non-woven fabric currently is the most commonly used reinforcement for this type of application.

Specimen Preparation

The emulsion was applied to fibre-reinforced cement substrates which had been specially treated to inhibit adhesion, and the non-woven fabric immediately was applied and embedded by brushing and rolling with a fluted roller to expel entrapped air. A coat of saturating emulsion then was applied to the fabric. The composite coating again was rolled with a fluted roller to ensure that the fabric was saturated, and the emulsion was allowed to dry. Then one or two top coats, depending on the prescription for each emulsion, were applied. For saturation and top coating, between 2.2 and 2.4 litres (0.054 and 0.059 gal/ft^2) of emulsion were used per square meter of fabric. After curing for 24 hours the samples were stripped from the substrate and cured for 28 days at 23C (73F) and 50 percent relative humidity.

Specimen exposure and testing

A set of samples was exposed for 1,000 hours in an Atlas 6500 Xenon lamp weatherometer (WOM) operating on a 102-minute light, and an 18-minute light and water spray cycle, at a black panel temperature of 65C (149F). A further set of laboratory samples was immersed in water for 28 days after curing.

Samples were collected from five different roofs, in the Pretoria area, which had been waterproofed with the five emulsion systems and the standard non-woven fabric from two to four years before. Pretoria is at latitude 25°45'S, longitude 28°14'E, is 1,370m (4,500 ft) above sea level, has an average annual rainfall of 720mm (28 inches) spread over a three-month wet, and a nine-month dry season. The average maximum temperature is 27C (81F), and the average minimum temperature is 3C (37F). There is an average of 8.9 hours of sunshine per day, and an average total solar radiation of 7 GJ/m^2 per year.

Tensile strength and elongation at break were determined on "dog bone" specimens, 12.7mm (0.5-inch) wide at the narrow point, using a tensile testing machine at an extension rate of 200mm per min (7.9 inches per min).

Tear strength was determined on specimens cut with die C, as described in ASTM D624. The width of each sample was 12.7mm (0.5-inch) at the 90 degree notch and the extension rate was 50mm per min (2 inch per min).

Average values of tensile and tear strength in the longitudinal direction are given in Tables 2 and 3. The average values obtained in the transverse direction were 20 to 30 percent lower and are not reported.

Impact resistance was determined using a 0.9 kg (2 lb) falling mass. Flexing samples through 180 degrees on a flexometer until breakage occurred measured flexural fatigue. The tests were repeated ten times for each composite material in both the longitudinal and transverse directions.

Water vapor transmission rates were determined in accordance with ASTM E96-81.

EXPERIMENTAL RESULTS AND DISCUSSION

Formulations

The most important component of a reinforced acrylic-based emulsion system is the emulsion itself. Table 1 shows the general formulation of the emulsions and their composition. In systems A, B and C the saturants and top coats had different formulations to promote saturation. Systems D and E used the same formulation for both saturant and top coat to facilitate application.The performance of these pure acrylic and styrenated-acrylic resins with respect to both mechanical properties and durability already had been established[5,6] and appropriate blends therefore were selected from those available.

The rheology of an emulsion is important because it governs, among other things, flow and saturating properties when forming part of a reinforced system. Ideally the viscosity, and thus the saturating efficiency, should be constant. Figure 1 shows that the viscosity of the different emulsions varied exponentially with the shear rate and was temperature dependent. Emulsions E and C had a lower viscosities and therefore better flow properties. They saturated the fabric more completely and produced more impermeable membranes as can be seen from their water vapor transmission and permeability properties given in Table 4.

Because the effect of temperature on viscosity is exponential relatively large changes in viscosity occur with relatively small changes in temperature. For this reason application at low temperatures should be avoided.

Mechanical properties

Table 2 shows that the tensile and tear strengths of all the acrylic emulsion systems are similar and better than those of bitumen impregnated felts. Elongations of the 5 reinforced acrylic emulsion systems are similar and much larger than those of the cellulose and glass fibre-based bitumen felts but less than those of the polyester reinforced felt. It must be noted that the elongation of unreinforced acrylic emulsion films is 200 to 300 per cent.[4] This demonstrates that the reinforcement determines the elongation of such composite systems.

The impact resistance varied between 2 and 3 joules (1.5 and 2.2 ft lb) for the five acrylic emulsion systems; 0.5 and 1.5 joules (0.4 and 1.1 ft lb) for single-layer paper and glass fibre felts; 20 and 30 joules (15 and 22 ft lb) for the 10mm (3/8-inch) thick, three-layer built-up paper and glass fibre based felts; and 4 and 6 joules (3.0 and 4.4 ft lb) for 4mm (3/16-inch) thick polyester based bitumen impregnated felt. The impact resistance of the thicker materials is higher.

The acrylic emulsion systems withstood 15,000 to 27,000 cycles of flexing in the fatigue tests, the single-layer paper and glass fibre-based felts 2 to 43 cycles, three-layer built-up paper and glass fibre felts 1 to 27 cycles and the polyester based bitumen impregnated felt 11,000 to 19,000 cycles. The systems reinforced with non-woven fabrics performed better.

Weathering and maintenance

Table 3 shows that exposure to accelerated artificial weathering conditions (WOM) did not affect elongation or tear strength and improved the tensile strength of the acrylic emulsion systems. This may result from the more complete curing of resins exposed to high doses of ultraviolet radiation. However, exposure to natural weathering conditions for two to four years caused a slight deterioration in mechanical properties. This may be ascribed to normal degradation and to the wet conditions which usually prevail under membranes laid on lightweight concrete screeds. To investigate the influence of wet conditions on the systems, samples were immersed in water for 28 days.

The results obtained indicate a decline in the mechanical properties. The properties of systems C and E were most affected by immersion in water. This shows that the combinations of resins used in these emulsions are softened by water. It therefore is essential to select the correct resins and additives if the optimum performance in terms of rheological properties, material strength, resistance to water and resistance to both accelerated and natural weathering is to be achieved.

Resistance to accelerated and natural weathering was good. No maintenance was needed on those systems which had been exposed to natural weathering for four years.

Permeability

Table 4 shows that the water vapor permeability of the systems A, B and D, formulated from pure acrylic resins, is higher than that of systems C and E. The latter emulsions possessed lower viscosities which helped achieve more effective saturation and thus a less permeable membrane. Table 4 also shows that the acrylic emulsion systems are much more permeable than the bituminous felts. This may be ascribed to the porosity of the reinforced acrylic emulsion systems which was confirmed by microscopic examination.

It must be pointed out that vapor permeability of a water proofing membrane can be an advantage. For instance, where water vapor becomes trapped under the membrane, it can escape slowly. However, the acrylic emulsion systems were found to be adequately watertight to perform satisfactorily as waterproofing membranes.

CONCLUSIONS

From this investigation the following conclusions can be drawn:

1. Compared to bitumen impregnated felts the reinforced acrylic emulsion systems have good mechanical properties and resistance to impact and fatigue. They allow transmission of water vapor but are sufficiently water-

tight to perform satisfactorily as waterproofing membranes. Their resistance to weathering is good and they require little maintenance.

2. The five specially formulated acrylic emulsions performed similarly except for the styrenated emulsions C and E whose resin blends were softened by prolonged immersion in water.
3. The rheology of an acrylic emulsion, which is temperature dependent, determines the saturation efficiency of the system. Such emulsions must be formulated for optimum rheological properties. Application at temperatures below 10C should be avoided.
4. At present there are no accepted norms for the saturation, thickness, physical properties or permeability of the reinforced acrylic emulsion systems. From these investigations[7] and from about eight years, practical experience, it is recommended that a reinforced acrylic emulsion system should conform to the properties in Table 5.

It is important to use correctly formulated emulsion and to saturate the non-woven fabric thoroughly during installation if the above norms are to be met. It is recommended that membranes be thicker than 1.5mm to avoid mechanical damage.

Practical experience also has contributed to the following observations:

1. The acrylic emulsions are water based which makes cleaning equipment and tools easy and also reduces environmental pollution. However they cannot be applied in wet weather, and will not tolerate even light rain immediately after application. High humidity retards, but does not inhibit, curing.
2. The drapeability of the saturated non-woven fabric enables the system to be applied over complicated shapes and in areas to which access is difficult.
3. Because these continuously bonded, seamless systems are compatible with, and adhere well to, a wide range of substrates, wind damage is not regarded as a problem.
4. The materials used in the system are combustible. However, the emulsions are highly filled and the systems are relatively thin. The contribution to the fire load will therefore be less than that of traditional materials which conform to fire regulations.

Reinforced acrylic emulsion systems possess better properties than most traditional waterproofing materials. If the recommendations which have been developed as a result of the investigations carried out to date[7] and current field experience, are applied to practice, a reliable, low maintenance, easy-to-install waterproofing system will result.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. P. Perlstein for the analysis of the acrylic emulsions, Mr. R.E. Cromarty for his continuous interest and advice and Dr. H.M. Saayman for his encouragement and assistance.

REFERENCES

1. Piazza, S. et al. 'Improvements in waterproofing membranes by modifying bitumen with thermoplastic polymer,' Poliplasti, 27(257):91-102, 1979. Translated by Nowacki, S. Technical translation 2011, Canada Institute for Scientific and Technical Information, National Research Council of Canada, Ottawa, 1982.
2. Bynoe, R. 'Alternatives to organic felts in BUR', Roof/Siding Insulation, August 1982, 72-84.
3. Krcma, R. Manual of nonwovens, Textile Trade Press, Manchester, England, in association with WRC Smith Publishing Co., Atlanta, USA, 1971.
4. Boyes, R.G.H. 'Geopolymer materials today.' Civil Engineering (London), Supplement to March 1981, 5-13.
5. Frank, D. 'Anti-corrosive water-emulsion paints for metal surfaces.' Journal of the Oil and Colour Chemists' Association, February 1960, 140-148.
6. Lavelle, J. 'New acrylics: high quality roof coatings.' Roofing/Siding/Insulation, February 1984, 100-106.
7. Smit, M.S. 'Waterproofing materials based on reinforced acrylic emulsions.' Second International Symposium on Plastics and Rubber Waterproofing in Civil Engineering, Liege, Belgium, 1984, 1.7.1-1.7.4.
8. Flueler, P. 'Plastic waterproofing membranes as building components testing and practical implications.' Second International Symposium on Plastic and Rubber Waterproofing in Civil Engineering, Liege, Belgium, 1984, 4.1.1-4.1.7.
9. Laaly, H.O. and Sereda, P.J. 'Limitations of present test methods for roofing materials.' Proceedings of the First International Conference on durability of building materials. ASTM Special Technical Publication 691, Ottawa, Canada, 1980, 755-766.
10. Cromarty, R.E. 'Glass reinforced polyester waterproofing.' RILEM-ICP-CEP International Symposium, Liege, Belgium, 1977, V.30.1-V.30.3.

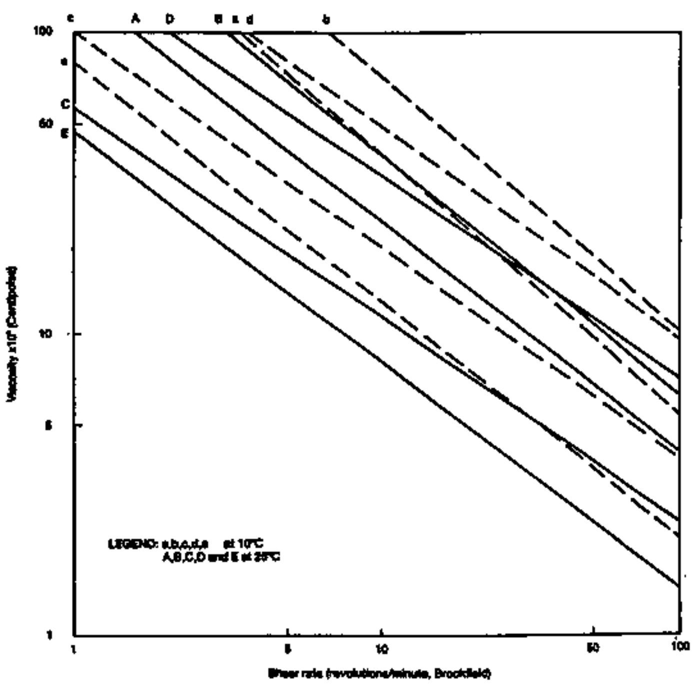

Figure 1 *Viscosities of acrylic based emulsions at 10C and at 25C*

Acrylic emulsions	Total solids content (mass/mass on wet mass) (%)	Filler* content (mass/mass on wet mass) (%)	Binder content (mass/mass on wet mass) (%)	Resins (binder)
A (saturant)	52.4	27.1	25.3	methylmethacrylate/ butylacrylate/butyl-methacrylate (≃ 47/47/6)
(top coat)	60.2	28.2	32.0	
B (saturant)	48.1	25.0	23.1	methylmethacrylate/ butylacrylate (≃ 50/50)
(top coat)	52.7	27.1	25.6	
C (saturant)	49.6	24.6	25.0	styrene butadiene/ methylmethacrylate/ butylacrylate (≃ 47/47/6)
(top coat)	60.7	30.5	30.2	methylmethacrylate/ butylacrylate/ butylmethacrylate (≃ 47/47/6)
D (saturant and top coat)	54.6	25.2	29.4	methylmethacrylate/ butylacrylate/ (≃ 50/50)
E (saturant and top coat)	51.6	24.1	27.5	styrene/butylacrylate butylmethacrylate (≃ 47/47/6)

*Materials such as calcium carbonate, iron oxide, titanium dioxide, slate dust and synthetic organic pigments were used in different combinations

Table 1 Properties of the acrylic emulsions used

Acrylic emulsion systems (see Table 1) reinforced with 150 ± 5 g/m² (5.3 ± 0.2 oz/ft²) polyester non-woven fabric	Thickness (mm)*	Tensile strength (MPa)**	Elongation at break %	Tear strength (N/mm)***
A	1.6	14.3	36	56
B	1.8	13.4	39	55
C	1.5	14.0	34	52
D	1.7	14.2	37	48
E	1.7	13.5	36	51
Bitumen impregnated cellulose felt	3.0	5.2	2	11
three layers built-up cellulose felt	10.0	5.0	3	15
glassfibre felt	3.0	2.7	3	9
three layers built-up glassfibre felt	9.0	3.1	4	13
polyester felt	4.4	2.6	67	19

* 1 mm = 40 mils
** 1 MPa = 145.03 lbf/in²
*** 1 N/mm = 5.71 lbf/in

Table 2 Thickness, tensile strength, elongation at break, and tear strength of 5 polyester reinforced emulsion systems, cured for 28 days at 23C and 50 percent relative humidity, compared with standard bitumen impregnated felts.

Acrylic emulsion systems (see Table 1) reinforced with 150 ± 5 g/m² (5.3 ± 0.2 oz/ft²) polyester non-woven fabric		Tensile strength (MPa)**	Elongation at break %	Tear strength (N/mm)***
A	(i)*	14.3	36	56
	(ii)*	15.3	33	50
	(iii)	13.5	34	53
	(iv)	10.1	25	40
B	(i)*	13.4	39	55
	(ii)*	14.6	35	52
	(iii)	12.0	31	45
	(iv)*	9.6	21	31
C	(i)*	14.0	34	52
	(ii)*	14.2	35	50
	(iii)	12.6	33	46
	(iv)*	7.1	21	41
D	(i)*	14.2	37	48
	(ii)*	14.8	33	44
	(iii)	12.6	31	38
	(iv)*	8.9	23	33
E	(i)*	13.5	36	51
	(ii)*	14.1	33	45
	(iii)	11.6	30	41
	(iv)*	6.7	21	30

* Samples prepared in laboratory (see Table 2)
* 1 MPa = 145.03 lbf/in²
*** 1 N/mm = 5.71 lbf/in

Table 3 Tensile strength, elongation at break and tear strength of 5 polyester reinforced acrylic emulsion systems. (i) original. (ii) exposed in a weatherometer for 1,000 hours. (iii) after 2 to 4 years natural exposure. (iv) immersed in water for 28 days.

Waterproofing materials	Water vapor transmission rate (g/m².24 hours)*	Water vapour permeability (g/m².24 hours.mm Hg) (metric perms)**
Acrylic emulsion systems		
A	9.7	0.91
B	8.6	0.81
C	2.8	0.26
D	9.3	0.87
E	2.1	0.20
Bitumen impregnated felt	0.01-0.05	0.0009-0.0047

*g/m².24 hours × 0.00249 = grains/ft².24 hours
**metric perms × 871.06 = perms

Table 4 Water vapor transmission and permeability for 5 polyester reinforced acrylic emulsion systems and bitumen impregnated felt

Mass of reinforcement (g/m²)	Saturation (ℓ/m²)	Thickness (mm)	Tensile strength (MPa)	Elongation at break (%)	Tear strength (N/mm)	Water vapor permeability (g/m².24 hours.mm Hg) (metric perms)	Impact resistance (Joules)	Fatigue resistance (cycles)
(a)	(b)	(c)	(d)		(e)	(f)		
>150	2.2-2.6	>1.5	>7	>20	>30	0.1-0.9	>2	>15000
>5.3 oz/ft²	0.054-0.059 gal/ft²	>60 mils	1.015 lbf/in²		>171 lbf/in	87-784 perms	(>1.5 ft. lb.)	

Table 5 Suggested performance properties of reinforced acrylic emulsion roofing systems