

Session 7a  
**NEW ANGLES ON HOT MIX**

## **Cold Asphalt Systems as an Alternative to Hot Mix**

**15**



**Sam Maccarrone** M Eng Sc, Grad Dip Proc Eng, B Sc  
**Principal Research Engineer**  
**Emoleum (Australia) Ltd**

**Glynn Holleran** B App Sc(Hons), M App Sc  
**Group Technical Manager**  
**Mobil Bituminous Products Group**

**Andy Ky** B Eng, Grad Dip Ind Chem  
**Research Engineer**  
**Emoleum (Australia) Ltd**

## SUMMARY

Cold technologies represent the future in road surfacing. Such systems are energy efficient and environmentally friendly. This paper examines developments in cold mixed asphalt based on the use of foamed bitumen and very high binder content emulsions. The improved aggregate-binder systems resulting can be used in both basecourse and wearing course applications. Presented in this paper are mix design considerations, mechanical properties and curing characteristics of these improved cold mixes.

## INTRODUCTION

Around the world the use of cold mixes for use on roadworks are gaining greater acceptance. This is due to environmental and economic considerations. Cold mixes do not emit hydrocarbons, use less fuel in manufacturing and production costs are lower. The most common form of cold mix is aggregate-emulsion system. This is becoming popular in Europe and this system was extensively reported on in Eurobitume (1993). The draw backs of such a system relate to cure time. Emulsions introduce high levels of water and this must be dried out for the system to attain full strength. Damage to pavement early in its life may occur due to either traffic stresses or rain. For this reason cold mixes have generally been restricted to low traffic roads.

This paper examines developments in cold mixed asphalt based on the use of foamed bitumen and very high binder content emulsions — both technologies developed by Emoleum in Australia. The improved aggregate-binder systems resulting can be used in both basecourse and wearing course applications. Presented in this paper are mix design considerations, mechanical properties and curing characteristics of these improved cold mixes.

## MANUFACTURING PLANT AND ECONOMICS

Manufacturing of cold mixes is much simpler and less costly than hot mix production. The aggregate may be used without being dried. Binders may be hot or cold, or a mixture of both. Manufacturing can be either at a central plant or in place using a mobile plant.

A basic manufacturing plant consists of hoppers for aggregate and filler coupled with a conveyor belt feeding into a pugmill. Spray bars are fitted for addition of water. The binder(s) are sprayed as the aggregate drops from the conveyor belt. Mixing efficiency of the pugmill is adjusted to ensure that binder distribution within the mix is homogeneous. The mixed material then drops onto a conveyor belt where it can be sent to a loading truck or to a silo for storage.

Production costs of cold mixes are less than hot mix. This is due to lower cost of plant set up, lower running cost (heating) and lower cost aggregate (recycle) can be used. For example it costs \$6 to \$7 per ton to dry aggregate for hot mix production. This is an immediate saving. Dryers/burners for hot mix plants require significant maintenance and drying drums must be larger for higher output pugmills. In cold plant systems, output is determined solely by conveyor speed and — pugmill capacity.

## MATERIALS

### Aggregate

Aggregate considerations are similar to those for hot mix. Both dense and open grading can be used and both have their advantages. However dense grading is generally used for both basecourse and wearing course application on the basis of lower permeability and higher modulus. Open graded mixes cure quicker due to higher voids, and for the same reason require to be sealed to prevent water entry.

Three aggregate sources, with typical gradings shown in Table 1 were used in the evaluation. These aggregates were:

- 20 mm hot bin aggregates — (A)
- 20 mm fine crushed rock — (B)
- 20 mm processed RAP — (C)

SIETE SIZE	25.5	19	13.2	9.5	6.7	4.75	2.36	1.18	600	300	150	75
	(mm)								(µm)			
SOURCE A	100	100	87	75	58	43	42	32	24	16	8	5.6
SOURCE B	100	100	92	73	63	58	44	28	17	14	11	8.0
SOURCE C	100	99	95	83	70	56	35	22	13	6	1	0.2

Table 1. Typical gradings of materials Percentage passing nominated sieve size

### Binders

Binder considerations are also similar to hot mix. The difference in cold systems is the method of delivery. Whilst foam utilises hot bitumen it is still considered a cold system as the resulting mix is stored and applied cold at the road site.

Three binders were evaluated and these consisted of a 60% emulsion, a very high binder content emulsion, EMOLSEAL™ and foamed bitumen. Typical residue of these binders is about 60%, 77% and 97%, respectively. EMOLSEAL™ due to its lower water and special formulation has quicker curing characteristics than 60% emulsions (Booth et al. 1994). Using a plate test to monitor cure, the rate of cohesion development is much higher with the higher binder content emulsion. This is shown in Fig. 1.

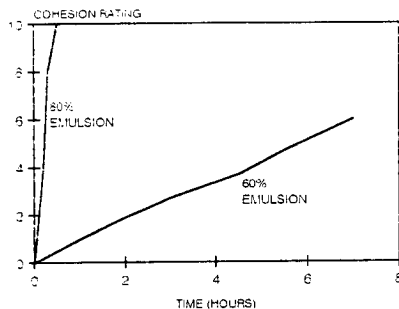


Fig. 1 Curing rate of two emulsions compared

Foamed bitumen provides an alternative to reducing the viscosity of bitumen without the use of cutters or

high levels of water (emulsions). Foamed bitumen is produced by injecting controlled amounts of water and additives into bitumen in a specially designed foaming chamber. The foam is characterised by volume expansion and half life (Maccarrone et al. 1994). In the highly expanded state successful coating of the aggregate occurs.

## MIX DESIGN

The characterisation of mixes made cold is identical to those for hot mix. Several parameters need to be considered in mix design to ensure that the final mix has optimised properties and that rate of cure and mechanical properties are suitable for the intended application. Outputs of a mix design will include mechanical properties as well as optimum contents of binder and moisture. Important parameters to be considered in mix design include:

- aggregate grading

Selection can be based on hot mix design experience or on volumetric design consideration. Dense grading is normally used.

- optimum moisture content

Moisture content of the aggregate prior to binder addition is critical to performance of a mixture. At optimum moisture content both dry density and modulus are maximised. The effect of water is to aid dispersion of the binder and assist compaction. However, excess moisture will prolong curing or make the mix unstable in early life.

- compaction

Laboratory compaction must simulate density achieved in the field. For thick layers (> 150 mm) this has been found to be 85 cycles of gyratory compaction with 240 kPa loading and 2° angle on 100 mm diameter specimens. For thinner layers, 120 cycles of gyratory compaction appears to be appropriate.

- curing

This needs to simulate both short term and long term curing in the field. Accelerated curing in the oven must be calibrated with field experience and with curing tests at ambient temperature. Three days curing at 60°C appears relevant for 12 months field curing for the binder systems reported in this paper. Oven cured samples gave similar modulus results as field cores taken 12 months after construction.

- mechanical properties

Mechanical characterisation of the mixes is carried out using a Materials Testing Apparatus (MATTA). Resilient modulus is determined at 25°C and rise time of 50 ms on both dry and "wet" conditioned samples. Wet conditioning consists of a one hour soak in water under vacuum. For complete characterisation creep and fatigue properties are required on cured samples.

- optimum binder content selection

The method used to determine optimum binder content depends on use of the material. One or more of the following parameters may need to be optimised: air voids, coating, film thickness, modulus and cost. Selection on the basis of air voids and coating and modulus were used in this investigation as these directly influence wearing course performance.

## AGGREGATE COATING

Aggregate coating is an important consideration for cold mixes. Aggregate coating is essential to ensure moisture resistance. The most critical aggregate fraction to be coated is the fine portion as this is most affected by moisture. For wearing courses, coating is required on all aggregate fractions. For base courses, coating of the larger size fraction is not as critical as long as construction ensures that an impermeable wearing course is laid and that drainage is adequate.

Binder dispersion in a mixture depends on aggregate surface area. Binder tends to coat the finer particles first, this means that the coarser particles have thinner films. This effect is experienced with emulsions and foamed bitumen, and the effect is exacerbated for higher viscosity binders.

### Method Used To Improve Aggregate Coating

A method used to improve aggregate coating consisted of separating the aggregated mixture into two size fractions (coarse and fine) and adding binder to each fraction separately. Typically the 4.75 mm sieve was used as the split point. The coarse fraction (material retained on the 4.75 mm sieve) was treated with emulsion and the fine fraction was treated with foam.

### Binder and water formulation for improved coating

For emulsions, lower viscosities are beneficial to coating. For 60% emulsions conventional cationic slow setting emulsions produce adequately low viscosity (about 30-50 cp at 25°C). For very high binder emulsions special emulsifier systems and appropriate particle size distribution (Booth et al., 1994) are required to keep the viscosity to appropriate lower levels. Very high binder content emulsions are preferably sprayed warm onto the aggregate to further aid the coating process.

For foamed bitumen, special surface active additives are used both in the bitumen phase and the water phase to produce a highly expanded and stable foam. Typically this means a volume expansion greater than 14 and a half life greater than 60 s.

Doping the water used to wet the aggregate with about 0.1% additive has been found beneficial in coating aggregate, especially when using foamed bitumen.

## PROPERTIES OF MIXES USING SPLIT AGGREGATE FRACTIONS

The method described above was used to improve aggregate coating. Emulsion was used to coat the coarse particles and foam to coat the fine fraction. Size 20 mm aggregate (source A) was used. Total binder ranged from 5% to 6%. Proportioning of binder on the two fractions was based on estimated surface area. Results are shown in Table 2. Air voids decreased from about 9% to 6% as the binder content was increased from 5% to 6%. Modulus remained relatively constant, marginally dropping as the binder content was increased. Dry and wet modulus were very similar indicating effective particle coating at all binder contents. Appearance of the samples with 6% binder was similar to hot mix.

TOTAL BINDER CONTENT, %	AIR VOIDS, %	RESILIENT MODULUS, MPa		APPEARANCE OF COMPACTED SAMPLE
		25°C AND 50 ms DRY	25°C AND 50 ms WET	
5	9.3	3120	2950	uncoated particles very apparent
5.5	7.7	2820	2740	improved coating, not complete
6	6.3	3050	2890	asphalt like

Table 2. Properties of mixes using split aggregate fractions

**CURING**

**Effect of binder type on curing rate**

The effect of binder type on curing rate was determined on 100% processed RAP (Source C). Two percent of binder was used for all mixes except the foam mixture. For the foam mixture 2% and 3% binder was used. Rate of curing rate was investigated at both ambient conditions (23°C and 60% humidity) and in the oven at 60°C. Prewetting of the RAP was done to achieve optimum moisture content (OMC) for each system. This meant adding 2% to 3% water to the RAP prior to adding the binder. Modulus results are shown in Table 3.

3 DAYS CURING AT 60°C		
RESILIENT MODULUS AT 25°C & 50 ms (MPa)		
BINDER TYPE & CONTENT	DRY	WET
2% FOAM	3100	1500
3% FOAM	2200	1100
2% CSS 60%	1500	1100
2% EMOLSEAL 80	1400	1100

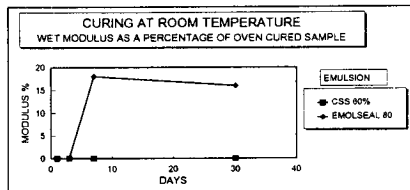
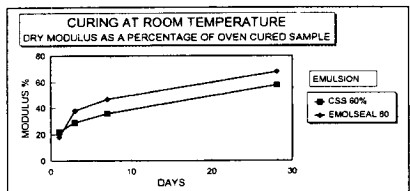


Table 3. Effect of Binder Type on Curing Rate

Results on oven cured samples (3 days at 60°C) indicated that the 2% binder was optimum for the foamed bitumen mixture. Dry modulus of the foamed

bitumen mixture (3100 MPa) was much higher than for the two emulsions (about 1500 MPa).

Results for curing at room temperature show that curing is faster with the higher binder content emulsion. Also resistance to moisture is higher with the high binder content emulsion. This is demonstrated by modulus measurement after wet conditioning. After 7 days curing, modulus is 0% and 20% of the oven cured sample for the 60% emulsion and for EMOLSEAL™ binders, respectively.

**Effect of fillers on curing rate**

Fillers have a marked effect on the curing rate of cold mixes. This appears to be due to a combination of cementitious effects and increase in surface area. This is illustrated for foamed bitumen mixes. A 20 mm fine crushed rock was treated with 2% foamed bitumen at OMC (6%). Fillers consisting of 2% cement works flue dust (CWFD), 2% hydrated lime and 1% cement were evaluated. After compaction the samples were removed from the mould and cured at room temperature (23°C, 60% humidity) for 1, 3, 7 and 30 days. The modulus was measured on both room temperature cured and oven cured specimens (3 days at 60°C).

Results are presented in Table 4. Addition of fillers such as CWFD and hydrated lime increase both the rate of cure and modulus (wet and dry) of the mixture. Cure rate of foamed bitumen with CWFD is very rapid achieving about 80% of its oven dry modulus after only one days curing at room temperature. Foamed bitumen mixtures for use on heavily trafficked roads always include fillers to improve the curing rate.

DAYS	RESILIENT MODULUS - DRY (MPa) at 25°C & 50 ms			
	NIL	CWFD, 2%	LIME, 2%	CEMENT, 1%
1	324	832	775	288
3	1025	4528	1111	1285
7	1913	4114	3388	2134
30	2500	3844	5285	2700

DAYS	RESILIENT MODULUS - WET (MPa) at 25°C & 50 ms			
	NIL	CWFD, 2%	LIME, 2%	CEMENT, 1%
1	415			860
7	391	1671	1662	1982
30	535	1907	2712	1800

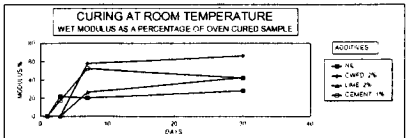
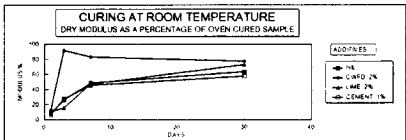


Table 4. Effect of Fillers on Curing Rate

## STORAGE STABILITY AND WORKABILITY

Laboratory testing and field experience (Durkin, 1993) has shown that cold mix produced with 4% foamed bitumen and 2% filler can be stockpiled for up to a month. For optimum storage stability water evaporation has to be minimised. This should be readily achieved with storage in silos. For storage in stockpile typical results show that after 10 days a wet modulus of 1500 MPa is achieved. After one month wet modulus drops to 500 MPa.

Stockpiled material will not wash out in rain as standard emulsion mixes will. This enables manufacturing several days prior to laying. Laying can be through a paver like hotmix or via simpler machinery. Remaining material can be stockpiled for future use.

Storage stability is advantageous in construction as the material can be reworked, if necessary, to ensure that required surface finish and levels are achieved. This enables for improved rideability to be achieved. Cold mixed asphalt is ideally suited for hand work at all temperature conditions. There is no problem with the mix becoming unworkable due to cold conditions.

## JOBS

Cold mixed asphalt based on foam bitumen formulations has been used on several jobs (Table 5) in the past year. Mixtures of 20 mm fine crushed rock aggregate were treated with 3.5% to 4% foamed bitumen and 1% lime and mixed in a central plant, transported to site and paver laid. Jobs consisted of road widening, deep patching and shoulder strengthening. All works were surfaced with either hot mix or a spray seal within a week of the cold mixed asphalt being placed. The works were opened to traffic soon after the compaction was complete without detriment to the surfacing.

JOB	VEHICLES PER DAY	TONS LAYED	DEPTH OF TREATMENT, mm	USE
Melba Highway, Vic	8,000	450	2 x 90	deep patching
South Gippsland Highway	15,000	300	200	shoulder widening
Meredith Highway, Col/Strat, Vic	8,000	250	150	road widening
Ryde City Council, NSW	1,000	800	2 x 100	road widening

Table 5. Jobs done with foamed bitumen mixes

For the work done at Melba Highway, 2 km north of Yarra Glen, the road was showing signs of rutting and cracking. In some sections the existing pavement consisted of a gravel base with a seal coat. Conventional rehabilitation using unbound material was found to be unsatisfactory as it resulted in major surfacing deterioration prior to placement of final surfacing.

A cold mixed asphalt alternative was tried. Two layers of 90 mm were compacted insitu. The deep patch was open to traffic three hours after placing. The surfacing was sealed one week later. Minor deterioration of the surfacing was observed on a few spots due to rain. This problem would not be expected to occur with the two stage mixing system mentioned earlier. Successful patching of these deteriorations was made one week

after construction using stockpiled material from the side of the road.

For the work at Ryde City Council cold mixed asphalt using 30% RAP and 70% base crushed rock mixture was used for road widening works. Manufacturing was at the Ryde Recycling Centre. The mixture consisted of 3.5% bitumen and 1% lime. The material was stockpiled and used within 7 days. The widening works consisted of 200 mm deep layers compacted in two layers. Asphalt overlay (25 mm) was used for the final surfacing.

For the work at Ryde, the cold mixed asphalt was used for two reasons:

- cost — this was less than half the cost of the conventional hot mixed asphalt treatment
- problems with conventional treatment — experience indicated that conventional treatment of lime modified sandstone (150 mm) and hot mix (150 mm) cracked early in its life.

## CANADIAN AND UK EXPERIENCE

Foamed bitumen mixtures have been used in road rehabilitation for almost 30 years. Resurgence of interest in its use over the past five years is due to several advantages including:

- environmental
- economic
- speed of construction
- simplicity of manufacturing process

In the eastern states of Canada Mobil licensees have used foamed bitumen mixture in recycling and reconstruction. Twin shaft pugmill has been used for manufacturing up to 500 tons/h. Production cost of the cold mixed asphalt is about half that of hotmix. For basecourse up to 100% RAP has been used. On a road trial in Alberta (Dawley et al. 1993) preliminary performance data indicated that 100 mm of the foamed mixture was structurally equivalent to about 85 mm of hotmix or 220 mm of crushed rock.

In the UK foamed bitumen mixtures are being used to rehabilitate light and heavy trafficked roads (Mix design uses Marshall methods). On a road trial on a heavily trafficked road (Department of the Environment, 1992), TRRL testing concluded the following:

- riding quality and general appearance of surfacing was satisfactory
- traffic disruption was minimal compared to alternative processes
- uniform compaction achieved throughout the 225 mm single layer
- excellent laboratory results for resistance to creep and fatigue
- faster construction period compared to conventional rehabilitation treatment. A factor of two was estimated.

## CONCLUSIONS

Cold mixed asphalt using foamed bitumen and very high binder content emulsions addresses the curing limitations of conventional cold mixes and as such offers an alternative to hot mixed asphalts. Associated

with this more rapid curing system are the following advantages:

- environmentally friendly
- curing faster than conventional cold systems
- cost effective
- quicker construction, lower traffic disruption
- extended workability
- material can be stockpiled
- simple manufacturing and construction equipment

Development of these mixes will yield functionally similar mixes to existing hot mixes at lower cost.

## REFERENCES

BOOTH E.H.S., HOLLERAN G., and MACCARRONE S. (1994) "Development of very high binder content

emulsions for sprayed sealing" Proceedings 17th ARRB Conf., Part 3, pp. 73-90

DAWLEY C. B., HOGeweIDE, B.L. and JOHNSTON A. G. (1993) Proceedings 38th Annual Conf. Canadian Technical Asphalt Association, pp 145-167

DEPARTMENT OF THE ENVIRONMENT (1992) "Monitoring of a cold road recycling process on a heavily trafficked road" New Practice Report NP/60. Department of the environment, UK.

DURKIN S.C. (1993) Project No 93/38, Internal Report, Mobil Oil Limited, London, UK.

EUROBITUME (1993). Proceedings 5th Congress, Vols 1a and 1b

MACCARRONE S., HOLLERAN G., LEONARD D.J. and HEY S. (1994) "Pavement recycling using foamed bitumen" Proceedings 17th ARRB Conf., Part 3, pp. 349-365