TECHNICAL ADVISORY GUIDE (TAG) FOR BONDED WEARING COURSE PILOT PROJECTS

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PREFACE

Highway agencies throughout the world face increasing demands and decreasing resources to maintain and preserve their highway networks. The demand to "do more with less" has been an operating slogan for many of these agencies. Historically, the emphasis has been on new facility construction, and rehabilitation or reconstruction of existing facilities. However, most agencies are currently in a maintenance and/or preservation mode, a trend that can be expected to continue in the foreseeable future.

Pavement preservation is a method by which roads are treated before significant failure has occurred. This has the advantage of allowing action before user complaints, and also saving the agency money over the life of the pavement.

This document was prepared by HQ Maintenance to assist in making better and more informed decisions on pavement maintenance practices. It should be of use to District Maintenance Managers, Maintenance Supervisors, Superintendents, and other field personnel. Construction personnel and designers may also find use for the information.

ACKNOWLEGMENTS

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1.0 INTRODUCTION

A bonded wearing course (BWC) is a gap graded, ultra thin hot-mix asphalt (HMA) mixture applied over a thick polymer modified asphalt emulsion membrane. The emulsion membrane seals the existing surface and produces high binder content at the interface of the existing roadway surface and the gap-graded mix all in one pass. The gap-graded HMA provides an open surface texture to allow water to flow through the surface. A BWC can be applied and opened to traffic quickly, usually within 15 minutes, without sanding or tracking. Bonded wearing courses are primarily used in high traffic areas as a surface treatment over HMA and PCC surfaces. It can be placed over structurally sound pavements as a maintenance treatment, and may also be used in new construction and rehabilitation projects as the final wearing course.

The BWC polymer modified asphalt emulsion membrane seals existing pavement and bonds the gap graded mix to the surface. The thick nature of the membrane allows it to migrate upwards into the mix, filling voids in the aggregate and creating an interlayer of high cohesion. Due to the nature of the gap graded mix and the polymer in the membrane, bleeding is not normally a concern.

The BWC gap graded mix provides a stone on stone contact which provides resistance to rutting within the mix. The finished mat has very high macro-texture properties, provides good skid resistance and has a void structure that improves driving visibility by reducing back-spray and tire-splash. The void structure also reduces tire noise. The mix is generally laid one and a half times as thick as the largest stone in the gradation, however, it may be placed thicker to correct minor surface irregularities.

Presently bonded wearing courses are used by Caltrans only on pilot projects. Also, bonded wearing courses are presently not used on quality control/quality assurance (QC/QA) projects. Nevertheless, due to the potential of BWC mixtures to extend the life of an existing pavement, coverage of this type of wearing course in this Advisory Guide is warranted.

This document provides an overview of:

- The materials used in construction of bonded wearing courses,
- Guidelines for project selection,
- The construction process associated with bonded wearing courses,
- A troubleshooting guide to assist the field personnel and
- Suggested construction field considerations.

2.0 DESIGN AND SPECIFICATIONS

2.1 GAP GRADED HOT MIX ASPHALT

This section provides an overview of, and specifications for, materials used in the construction of bonded wearing courses. Bonded wearing courses are constructed using polymer-modified binders and gap graded aggregates. More detailed information may be found in the Standard Special Provision SSP 39-700 A-10-01-01 (1). The purpose of using a gap grading in a BWC is to provide improved stone-to-stone contact by reducing the medium sized aggregate content. This also produces a strong aggregate skeleton that provides space for more engineered binder than a dense graded mix does.

2.1.1. Binder

Currently, there are four grades of binder approved in the Caltrans specification for use in BWC construction. They are listed in Table 1. They vary in their degree of polymer modification, and their use corresponds to the climatic conditions encountered in California. In general terms, grades GGB1 and GGB2 are used in hotter climates, while grades GGB3 and GGB4 are used in cooler climates.

Table 1: Bonded Wearing Course Hot Mix Binder Grades

BINDER GRADE	GENERAL CLIMATIC REGION	CRITERIA
GGB1	Desert or Hot Valley Areas and Coastal Areas	Areas below 1,050 m (3,445 ft) elevation with average 7-day maximum and 1-day minimum pavement temperatures between 70°C and -22°C (158°F and -8°F), respectively.
GGB2	Coastal Areas	Areas below 1,050 m (3,445 ft) elevation with average 7-day maximum and 1-day minimum pavement temperatures between 64°C and -22°C (147°F and -8°F), respectively.
GGB3	Cool Coastal or Mountain Areas	Areas below 1,500 m (4,920 ft) and above 1,050 m (3,445 ft) elevation with average 7-day maximum and 1-day minimum pavement temperatures between 64°C and -28°C (147°F and -18°F), respectively.
GGB4	Mountain Areas	Areas above 1,500 m (4,920 ft) elevation with average 7-day maximum and 1-day minimum pavement temperatures between 58°C and -34°C (136°F and -29°F), respectively.

Table 2 shows the specification for the binders used in bonded wearing courses. It should be noted that a performance-based system using rheological measurements is employed. Higher stiffness binders are used for hotter climates while lower stiffness binders are used for cooler ones. The viscosity is used to control the application of the binder.

Table 2: BWC Hot Mix Binder Requirements (1)

SPECIFICATION DESIGNATION	TEST METHOD	GGB GRADES			
		1	2	3	4
Flash Point, Cleveland Open Cup, ˚C, min., original binder	AASHTO T48	230	230	230	230
Brookfield Viscosity, max. 2.0 Pa s test temperature, ˚C	ASTM D 4402	135	135	135	135
Elastic Recovery after RTFO test % min	AASHTO T 301-99	60	60	60	60
Mass Loss after RTFO test, % max	AASHTO T240	0.6	0.6	0.6	0.6
Dynamic Shear, G*/sin˚, min. 2.2 kPa RTFO aged residue, test temperature at 10 rad/sec, ˚C	California Test 381 Part 3	70	64	64	58
Residue from PAV, test temperature, ˚C	AASHTO TP1-98	110	100	100	100
Creep Stiffness, 300 MPa, Max. and M-value, 0.30, Min. residue from PAV, test temperature ˚C	AASHTO TP1-98	-12	-12	-18	-24
REPORT ONLY					
Dynamic Shear, SSD $\geq$ 30 x (0.6 + SSV)3 original binder, ˚C	California Test 381 Part 1	25	25	25	25
Dynamic Shear, SSD $\geq$ -115 x (SSV) - 50.6 On PAV aged residue, from AASHTO PP1, ˚C	California Test 381 Part 1	25	25	25	25

2.1.2. Aggregate

The main properties of the aggregate used in BWC mixtures include gradation, shape, number of crushed faces, wear resistance and clay or deleterious material content.

The two gradations allowed in BWC mixtures are shown in Tables 3a and 3b. In the tables, the symbol "X" is the gradation that the Contractor proposes to furnish for the specific sieve listed. However, the proposed gradation shall meet the gradation shown in the "Limits of Proposed Gradation".

The 12.5 mm ($^1/_2$ in) gradation is used for roadways with high traffic volumes (which require a thicker and more durable mat) *and* where pedestrian or bicycle traffic are not a concern. The 9.5 mm ($^3/_8$ in) gradation is used for urban, residential and business district roadways where pedestrian and bicycle traffic is a consideration. This can also be used on mainline travel ways if desired.

The physical property requirements of the aggregate used in BWC mixtures are shown in Tables 4a and 4b. The requirement listed in Table 4b only applies when studded tire or chain wear is a concern.

Table 3a: Gradation, Maximum 12.5 mm (½ inch) (1)

PERCENTAGE PASSING, 12.5 MM MAXIMUM			
SIEVE SIZES	**LIMITS OF PROPOSED GRADATION**	**OPERATING RANGE**	**CONTRACT COMPLIANCE**
19 mm	—	100	100
12.5 mm	—	85-100	82-100
9.5 mm	60-80	X±5	X±8
4.75 mm	28-38	X±4	X±8
2.36 mm	25-32	X±4	X±6
1.18 mm	15-23	X±3	X±5
600 µm	10-18	X±3	X±5
300 µm	8-13	X±3	X±5
150 µm	—	5-11	4-12
75 µm	—	3-8	2-9

Table 3b: Gradation, Maximum 9.5 mm ($^3/_8$ inch) (1)

PERCENTAGE PASSING, 9.5 MM MAXIMUM			
SIEVE SIZES	**LIMITS OF PROPOSED GRADATION**	**OPERATING RANGE**	**CONTRACT COMPLIANCE**
12.5 mm	—	100	100
9.5 mm	—	85-100	82-100
4.75 mm	28-38-	X±4	X±8
2.36 mm	25-32	X±4	X±6
1.18 mm	15-23	X±3	X±5
600 µm	10-18	X±3	X±5
300 µm	8-13	X±3	X±5
150 µm	—	5-11	4-12
75 µm	—	3-8	2-9

The aggregate specifications are provided to obtain desired mix properties. For example, the mixture is intended to interlock and develop a shear-resistant pavement surface; hence, crushed particle faces are essential. The gap-graded aggregate creates voids in the aggregate, which ensure the correct void level in the mix. Flat or elongated particles reduce texture depth and are to be avoided. The aggregate should also be wear resistant (low wear value in CT 211) and low in clay content (high Sand Equivalent value using CT 217).

Table 4a: Required Aggregate Properties for a BWC (1)

TEST	TEST METHOD	REQUIREMENT
Percentage of Crushed Particles:		
Coarse Aggregate, %, minimum	California Test 205 (*Note a*)	90
Fine Aggregate (On portion passing a 4.75 mm sieve and retained on a 2.36 mm sieve), %, minimum	California Test 205 (*Note a*)	85
Uncompacted Void Content, %, minimum (*Note b*)	AASHTO T304 Method A	45
Flat & Elongated Ratio at 3:1, %, maximum	ASTM D 4791	25
Los Angeles Rattler: Loss at 500 rev., %, maximum	California Test 211	35
Sand Equivalent:		
Contract Compliance, minimum	California Test 217	47
Operating Range, minimum	California Test 217	50

Notes:

a) In California Test 205, Section D, the definition of a crushed particle is revised as follows: "A particle having two or more fresh, mechanically fractured faces shall be considered a crushed particle."

b) If the fine aggregate is 100% crushed, the use of crushed material shall be monitored during the production process. If the fine fraction is a combination of crushed and natural materials, the fine aggregate angularity (FAA) shall be monitored during the process.

Table 4b: Additional Aggregate Requirements for BWC Applications (1)

SPECIFICATION	REQUIREMENTS
Surface Abrasion Test, California Test 360, maximum loss	0.40 g/cm^2

2.1.3. Mix Design

The performance of a bonded wearing course depends on the quality of the materials and how they interact during application, rolling and after opening to traffic. The amount of polymer modified asphalt binder to be mixed with the aggregate for gap-graded polymer modified asphalt concrete shall be determined by the Contractor using Asphalt Institute MS 2 Table 6.1. The binder content shall be established based on an estimated film thickness minimum of 10 microns. Film thickness will be calculated based on effective asphalt content. The optimum binder content is first established so that the film thickness requirement is met. This binder content shall conform to the draindown and film stripping requirements. The film thickness is optimized and the resistance to stripping by the action of water is measured. These properties are important in gap-graded mixes, as water has easy access to the binder-aggregate interface. Table 5 lists the BWC mix requirements.

Table 5: BWC Mix Requirements (1)

TEST	TEST METHOD	REQUIREMENT	
		MIN	MAX
Film Thickness, μm	Gradation surface area factor method; Asphalt Institute MS-2, Table 6.1	10.0	-
Film Stripping, %	California Test 302	-	25
Drain down Test, g	California Test 368	-	4

2.2 POLYMER-MODIFIED ASPHALT EMULSION MEMBRANE

The asphalt emulsion used in the membrane for a bonded wearing course is specially formulated and must meet the specification detailed in Caltrans SSP 39-700_A10-01-01 (1). The binder is designed to give high flexibility and bonding in the range of climactic conditions in which bonded wearing courses are placed (see Section 2.1.1). The emulsion is manufactured using conventional means.

Specifications are based on standard emulsion specifications; such as, stability, binder content, viscosity and torsional recovery. Application viscosity is important, as the material should be easily sprayed at the correct rate, not flow away and form a continuous membrane. The residual properties indicate polymer presence and the base asphalt grade used. Cooler conditions call for higher residual penetration. The emulsion is designed to break rapidly after spraying to ensure that no water is trapped. The gap-graded nature of the mix allows water to escape, thus promoting breaking of the emulsion.

Table 6: BWC Emulsion Specifications (1)

SPECIFICATION DESIGNATION	TEST METHOD	REQUIREMENT	
		MIN.	MAX.
Saybolt-Furol Viscosity, at 25°C, s	AASHTO T59	20	100
Sieve Test on original emulsion (at time of delivery), %	AASHTO T59	-	0.05
24-hour Storage Stability, % (*Note a*)	AASHTO T59	-	1
Residue by Evaporation, %	California Test 331	63	-
Solubility in Organic Solvent, % (*Note b*)	AASHTO T44	97.5	-
Torsional Recovery, measure entire arc of recovery, at 25°C, %	California Test 332	30	-
Penetration (0.01 mm) at 25°C			
Emulsion used with GGB1 or GGB2	AASHTO T49	70	150
Emulsion used with GGB3	AASHTO T49	90	180
Emulsion used with GGB4	AASHTO T49	100	200

Notes:
a) After standing undisturbed for 24 hours, the surface shall show no white, milky colored substance, but shall be a smooth homogeneous color throughout.
b) The organic solvent shall be from the approved list available from the Transportation Laboratory.

3.0 PROJECT SELECTION

3.1 DISTRESS AND APPLICATION CONSIDERATIONS

While a bonded wearing course is a flexible pavement surface, it is not considered a structural layer. A BWC is a viable application for treating structurally sound, worn pavements and has shown some ability to retard cracking due to its membrane and gap-graded aggregate structure. BWC's are used on both flexible and PCC pavements to correct non-structural surface defects such as skid resistance, noise dampening and splash-and-spray control. They are typically selected for use when speed of construction and user delay are issues. Table 7 outlines the allowable surface distress' on which a BWC can be placed. Note that the definitions of pavement condition in Table 7 are taken from SHRP Manual P-338 (2).

Table 7: Distress Severity or Extent That Can Be Treated With a BWC (3)

PAVEMENT TYPE	CRACKING	PATCHING/ POTHOLES	SURFACE DEFORMATION	SURFACE DEFECTS	JOINT DEFICIENCIES
AC	1. Longitudinal & Transverse (Medium) 2. Block (Moderate) 3. Edge (Moderate)	Patches: Moderate Potholes: Moderate	Rutting: <12.5 mm Shoving: No	Bleeding Moderate Polished Agg: OK Raveling: Severe	N/A
PCC	1. Corner Breaks (Moderate) 2. Materials Related Distress (Low) 3. Longitudinal (Moderate) 4. Transverse (Moderate)	N/A	N/A	Map cracking and scaling: <10 m^2 to 100 m^2	Spalling: Moderate
Note: For PCC, a BWC will not treat blowups, pumping, faulting of joints, or crack widths > 9.5 mm					

3.2 PERFORMANCE

3.2.1 Performance

Bonded wearing courses have been estimated to last 7 to 12 years (4,5,6). The main method of failure is wear; that is, the surface oxidizes and is abraded over time. Premature failure occurs from placement on highly deflecting and cracked surfaces, base failures and delamination occur when placed on dirty or poorly prepared surfaces.

The main performance benefits associated with using a BWC are improved skid resistance, reduced traffic noise, increased ride quality and spray reduction. Figures 1 and 2 shows how the characteristics of a BWC compare with those of other mixture types (4,5,7). The figures indicate that a BWC retains good skid resistance characteristics over time and that it is comparable to other wearing courses that provide good skid resistance characteristics. The skid resistance of a BWC varies with increasing speed in a manner similar to stone mastic asphalt (SMA) as shown in Figure 2.

It can be seen that BWC's rate well in comparison to other surface treatments. The data listed in Table 8 has been collected from several sources (4,8). Splash and spray are important surface characteristics and may be measured in various ways. One method is by hydraulic conductivity. This is done by pressing a special cylinder against the road surface and measuring conductivity. A high number represents faster drainage. Table 8 shows the results of hydraulic conductivity tests performed on three surface treatments. As the results indicate, BWC's had the highest drainage characteristics of the three surface treatments types tested.

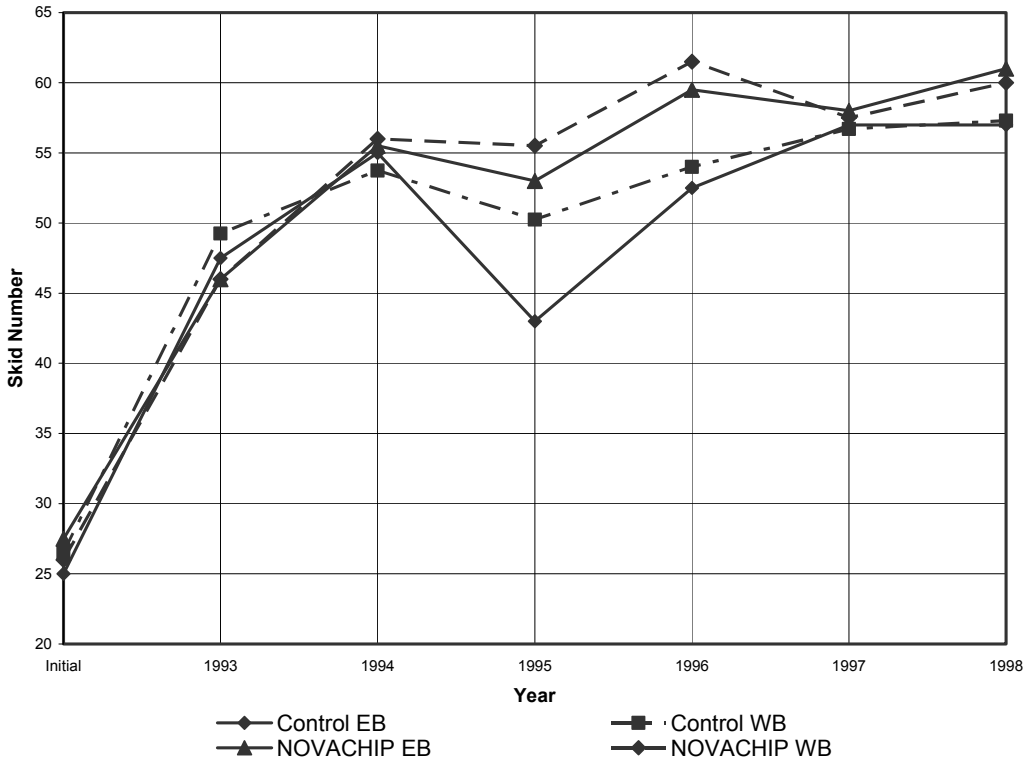


Figure 1: Change in Skid Resistance Over Time (5)

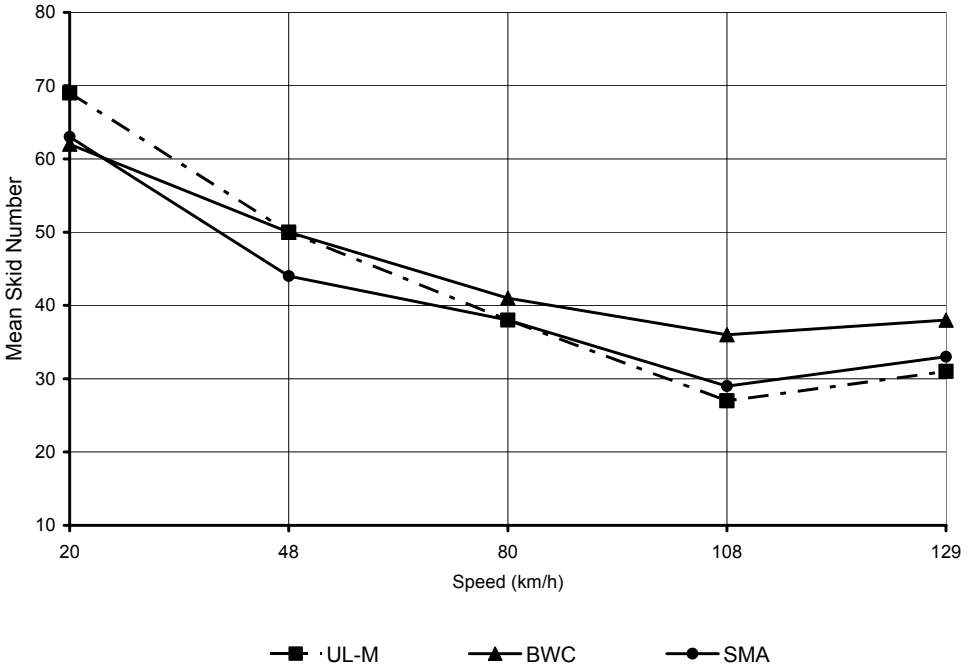


Figure 2: Change in Skid Resistance with Speed (4)
(UL-M is Ultra Thin Polymer Modified HMA – 25mm)

Table 8: Hydraulic Conductivity as an Indication of Spray Reduction Characteristics (4)

MATERIAL	HYDRAULIC CONDUCTIVITY (S^{-1})
14 mm SMA	0.03
12.5 mm BWC	0.06
10 mm UL-M	0.01
12.5 mm OGAC	0.12

3.2.2 Relative Cost Effectiveness

To date, Caltrans has only used BWC's on pilot projects since the product is new. The costs have been variable and have ranged from $40M to $50M per lane mile (LM). However, in other states the costs have been as low as $21M per LM (9). Costs for BWC's vary depending on the materials used (night work vs. day work, quantities, work windows) and the locations in which they are placed. Recently a Caltrans project was estimated to cost $35M per lane mile so cost has decreased as more projects are planned. This is typical of any new process coming into the market.

4.0 CONSTRUCTION OF BONDED WEARING COURSES

The main components of the construction process include:

- Safety and Traffic Control
- Equipment Requirements
- Mix Production and Handling
- Surface Preparation
- Application Conditions Required
- Application of BWC
- Opening to Traffic

Appendix A, "Suggested Field Considerations", at the end of this chapter, provides a series of tables to guide project personnel through the important aspects of constructing a BWC.

4.1 SAFETY AND TRAFFIC CONTROL

Traffic control is required both for the safety of the traveling public and the personnel performing the work. It is also used to ensure the new surface is compacted and allowed to cool to below 70°C (158°F) prior to reopening the surface to traffic.

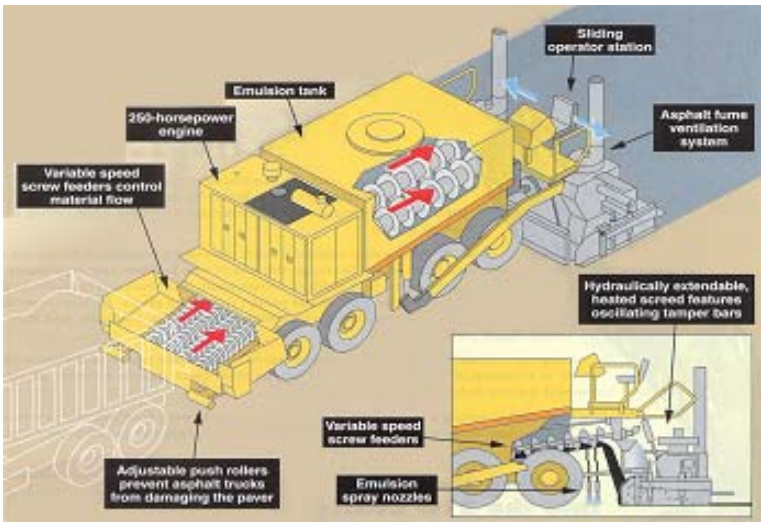
Traffic control should be in place before work forces and equipment enters onto the roadway or into the work zone. Traffic control includes placing construction signs, construction cones and/or barricades, flag personnel, and pilot cars required to direct traffic clear of the maintenance operation. For detailed traffic control requirements, refer to the Caltrans project specifications and the Caltrans Code of Safety Operating Practices (10).

4.2 EQUIPMENT REQUIREMENTS

Equipment requirements for constructing a BWC are found in SSP 39-700_A10-0101 (1). The most significant requirement is that the binder application and hot mix spreading function are combined into a single unit. The following section describes this specialized unit while the subsequent sections discuss other equipment requirements.

4.2.1. Paving Unit

The paving unit used for the construction of a BWC is a specially constructed machine. A diagram of a BWC paving unit is shown in Figure 3. Figure 4 shows a close up of the spray and spreading functions of a BWC paving unit, and Figure 5 shows a freshly laid BWC.



- The paving unit pushes the truck carrying the hot mix asphalt.
- The mix drops into a hopper at the front of the paving unit.
- The mix is transported via an auger to a screed.
- The emulsion membrane is sprayed just in front of the screed and the mix is laid on top.

Figure 3: Paving Unit (2)

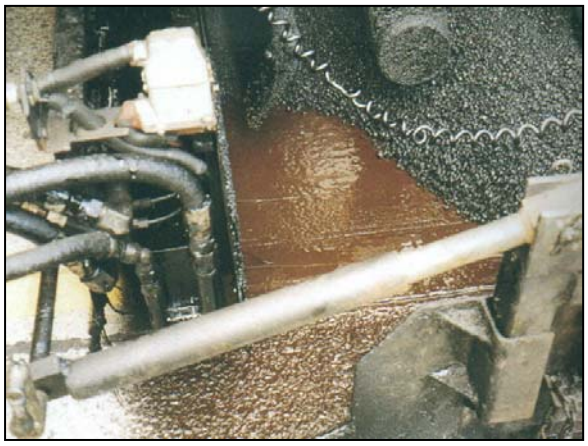


Figure 4: Emulsion Membrane and Mix Spreading (11)

Figure 5: Freshly Laid BWC (11)

4.2.2. Rollers

Compaction of a BWC is required. Static and steel drum type rollers, only, should be used. The rollers must be at least 12 tons and must conform to the Caltrans Standard Specifications Section 39-5.02, "Compacting Equipment" (12). Compaction must conform to Caltrans Standard Specifications Section 39-6.03, "Compacting" (12) and shall consist of two coverages' before the temperature of the

mat falls below 90°C (194°F). If necessary more than 2 coverage's may be ordered by the Engineer when rolling bonded wearing course patches or joints. Rolling of the gap-graded mixture is intended to seat the aggregates and to provide a smooth surface. There are no in place density requirements when rolling bonded wearing course mixes.

4.2.3. Other Equipment

Other required equipment includes sweepers for cleaning the pavement before application and hand tools such as rakes, shovels etc.

4.3 MIX PRODUCTION AND HANDLING

Standard hot mix facilities and storage bins may be used for BWC mix production, as outlined in Caltrans Standard Specifications 39-3.04, "Mixing" and Section 39-3.01 "Storage", respectively (12). The only special requirements are that the mixing temperatures for a BWC shall not exceed 177°C (351°F) and storage time shall not exceed 12 hours. A drain down test should be performed to ensure binder does not drain out of the mixture. All mixing plants must be calibrated to California Test Method CT 109. BWC mixes may be treated with an anti-stripping agent or lime if required, but the District Materials Engineer must approve this.

4.4 SURFACE PREPARATION

Cracks greater than 6 mm wide ($^1/_4$ in) should be filled or sealed prior to application see Chapter 3 (Crack Sealing and Filling) of this document. The use of over-banding methods of crack sealing is not recommended for this treatment as that method can leave strips that reflect through the finished pavement. All repairs necessary to bring the pavement to the minimum requirements listed in Table 7 must also be performed prior to the application of the BWC.

Manhole covers, drains, grates, catch basins, and other utility services must be covered prior protected from the application of the BWC. Covering the services with construction paper or roofing felt can do this. Any surface irregularities deeper than 25 mm (1 in) should be filled with dense graded hot mix before applying the BWC. Prior to application, the pavement should be swept with a rotary broom equipped with metal or nylon broom stock.

4.5 APPLICATION

Application of a BWC requires the use of a specialized paving unit described above in Section 4.2.1. Additional details specific to placing bonded wearing courses are discussed in the following paragraphs.

4.5.1. Conditions Required

A BWC may be applied on damp, but not wet, surfaces. The minimum air and pavement temperature requirements are 7°C (45°F) and rising, although it is recommended that the surface temperature be above 15°C (59°F). No freezing conditions are allowed in the first 24 hours, the emulsion-based tack coat requires about one day to fully cure. Additionally, if the water in the emulsion freezes, it may rupture the bond between the pavement and the new mix.

4.5.2. Polymer Modified Asphalt Emulsion Membrane

The emulsion applicator is part of the paving equipment and applies the polymer modified emulsion membrane at a temperature between 40° and 85°C (104° and 185°F) at a rate of 0.6 to 1.2 liter/m^2 (0.13 to 0.3 gal/yd^2). An emulsion application shot rate of 0.9 liter/m^2 (0.2 gal/yd^2) can be considered typical when using a 12.5 mm gap-graded mix gradation. An emulsion application shot rate of 0.77 liter/m^2 (0.17 gal/yd^2) can be considered typical when using 9.5 mm gap-graded mix gradation. The application rate should be adjusted according to the surface being covered. For more absorbent or textured pavement surfaces, a higher application rate by as much as 0.4 liter/m^2 (0.17 gal/yd^2) extra emulsion can be used when dealing with badly pocked pavement surfaces. For very smooth pavements, a reduced application rate by as much as 0.27 liter/m^2 less emulsion can be used when dealing with flushed asphalt concrete pavements or smooth Portland cement concrete pavements. Typically PCC pavements require less emulsion membrane than AC pavements

If the screed extension is outside the spray bar width, the tack coat will need to be applied manually to coat the pavement between the end of the spray bar and the end of the screed. Care should be taken to ensure the correct application rate in such circumstances. The spray bar should be calibrated and able to be adjusted to within ± 10% of the design application rate. Coverage of the pavement must be even and uniform and, as such, it is important that there are no plugged nozzles on the spray bar.

4.5.3. Paving

Good paving practice should always be followed when constructing a BWC. Windrowing and pick up machines are not allowed for constructing bonded wearing courses. The trucks servicing the paving unit should operate in a smooth manner, causing no bumps and allow paving to proceed continuously to create a smooth ride.

A BWC may be placed in lifts from 12 to 40 mm (1/2 to $1^1/_2$ in) thick when using a 9.5 mm ($^3/_8$ in) mix. Thicker lifts are allowed when using a 12.5 mm ($^1/_2$ in) mix. The spread rate associated with using a 9.5 mm ($^3/_8$ in) mix is from 36 to 47 kg/m^2 (7 to 9.5 lb/ft^2) and 44 to 55 kg/m^2 (9 to 11 lb/ft^2) when applying a 12.5 mm ($^1/_2$ in) mix. The minimum delivery temperature for a BWC is 135°C (275°F), with an upper temperature limit of 177°C (351°F).

Longitudinal joints should be straight or correctly aligned to the curvature of the roadway, and should occur only at the edge or center of a traffic lane and never in the wheel paths.

At the start and finish of the work, the existing flexible pavement should be cut out to a depth of 30 mm (1.2 in) and tapered back a distance of 3m (10 ft) to provide a key for the new surfacing. For PCC, the mix should be rolled over at the start and finish of the work. The end of each run should be squared off at the point where feathering commences, and the feathered material should be cut out before the next run is started. Figure 6 illustrates the method for making transverse butt joints between runs. Handwork should always be minimized.

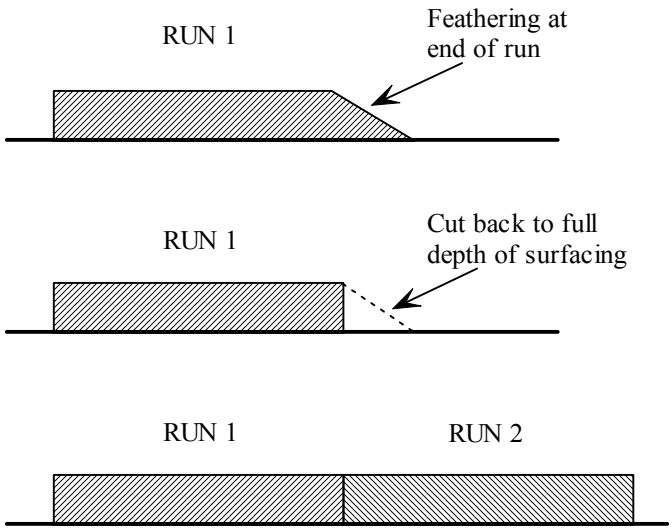


Figure 6: Making Transverse Butt Joints (9)

4.5.4. Rolling

A minimum of one steel drum tandem roller is required for compacting a BWC. **Rollers must be operated in static mode only.** Usually two passes using a 12 to 15 ton roller is sufficient to properly seat the aggregates. Rolling must be carried out before the temperature, at mid layer of the mix, falls below 90°C (194°F) (1). Figure 7 shows roller positions relative to the paver.

Figure 7: Roller Position During Application (11)

4.6 OPENING TO TRAFFIC

Traffic can be allowed onto the new surface once rolling is completed and the mix temperature has fallen below 70°C (158°F). Typically, no post sweeping is required unless the mix begins to ravel.

5.0 TROUBLESHOOTING

This section provides information to assist the maintenance personnel with troubleshooting problems that may arise when applying a BWC. Table 9 lists some commonly encountered problems and their recommended solutions.

Table 9: Common Problems and Related Solutions

PROBLEM	SOLUTIONS
SURFACE WAVES	▪ Ensure the head of material in front of the paver screed is at the correct height and does not fluctuate (i.e., rise and fall). ▪ Ensure the screed is not worn or set incorrectly. ▪ Ensure the mix is not too stiff or has not fallen below 135°C (275°F). ▪ Ensure the dump trucks do not bump the paving unit as this can cause long frequency waves resulting in increased pavement roughness. ▪ Ensure grade control equipment (if in use) is functioning properly
WASH BOARDING	▪ Slow roller down.
TEARING	▪ Ensure the paving unit is being operated correctly. ▪ Ensure the mix is not too cold (i.e., below 135°C (275°F)) or too stiff. ▪ May be fixed by adjusting the degree of crown and ensuring mix temperature is correct. ▪ Ensure application is not too thin
NON UNIFORM TEXTURE-SEGREGATION	▪ Ensure the mixture is not separating in the hopper or during transportation. ▪ Ensure the paving unit is set up properly. ▪ Ensure the mix temperature is at least 135°C (275°F). ▪ Check the mix design for poor grading. Adjust if necessary.
SCREED MARKS	▪ Ensure the paving unit is set up correctly and that the screed in not worn or dirty. ▪ Ensure the mix temperature is at least 135°C (275°F). ▪ Check the mix design for poor grading. Adjust if necessary. ▪ Ensure mix is in specification.
ROLLER CHECKING & MARKS	▪ Ensure the roller does not cause a wave in the mat in front of the roller (i.e., mix too hot). Wait until the mix cools further. ▪ Check the mix design for too much asphalt in the mix, or too much middle size sand in the gradation. Adjust design if necessary.

Table 9: Common Problems and Related Solutions (cont.)

PROBLEM	SOLUTIONS
BLEEDING & FAT SPOTS	▪ Ensure the mix temperature is not too hot (greater than 177°C (351°F). ▪ Check the mix design for too much asphalt or for too coarse an aggregate grading. Adjust design if necessary. ▪ Ensure there is no moisture in the mix or on the pavement. ▪ Ensure the tack coat application rate is not too high for the surface to which it is applied. Tight, smooth surface require less tack coat than do more open surfaces. Reduce application rate on existing surfaces that exhibit bleeding. ▪ Ensure spray bar equipment is operating properly. ▪ Ensure aggregates are dry before mixing with asphalt in the hot mix plant, that pavement is not bleeding, that pavement is dry, and that mix is correctly designed for traffic and aggregate.
DELAMINATION	▪ Ensure adequate tack coat is applied. ▪ Ensure the mix is above minimum application temperature (135°C (275°F)). ▪ Ensure the mix is not below the minimum compaction temperature (90°C (194°F)). ▪ Ensure the existing pavement surface temperature is above the minimum (i.e., 7°C (45°F)) before paving. ▪ Ensure the surface is cleaned immediately before paving. ▪ Ensure roller drums are not dirty and have working spray systems.
POOR TRANSVERSE JOINTS	▪ Ensure butt joints are properly constructed.
POOR LONGITUDINAL JOINTS	▪ Ensure proper joint construction practices are followed, especially when compacting thin layers.
EXCESSIVE RAVEL	▪ Ensure the mix design meets project specifications, particularly that the mix contains sufficient binder. ▪ Ensure compaction is carried out above the minimum temperature (i.e., 90°C (194°F).

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APPENDIX A

SUGGESTED FIELD CONSIDERATIONS FOR BONDED WEARING COURSE

The following field considerations are a guide to the important aspects of applying a bonded wearing course. The tables list items that should be considered in order to promote a successful job outcome. As thoroughly as possible the answers to these questions should be determined, as required, before, during, and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff members. The field supervisor should be acquainted with its contents.

The intention of these tables is not to form a report, but to highlight important aspects and components of the BWC construction process. Some information is product-specific and contained in the relevant standard specifications, special standard provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	▪ Is the project a good candidate for a bonded wearing course? ▪ How much rutting is present, depth and extent? ▪ How severe and what type of cracking exists? ▪ Is crack sealing needed? ▪ Is the pavement surface waterproof? ▪ How much bleeding or flushing exists? ▪ Is pavement raveling or oxidized? ▪ What is the traffic level? ▪ Is base sound and well drained? ▪ Is surface water splash-and-spray a problem? ▪ Is pavement strengthening required? ▪ Review project for bid/plan quantities.
DOCUMENT REVIEW	▪ Application specifications. ▪ Mix design information. ▪ Special provisions. ▪ Construction manual. ▪ Traffic control plan (TCP).
MATERIALS CHECKS	▪ Have the aggregates been sampled and tested? Do they meet the requirements set forth in the Standard Special Provision? ▪ Has the binder for the mix been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision? ▪ Is the mix produced by an approved source? ▪ Has a full mix design has been performed for the mixture? ▪ Has the mix been tested? Is the mix within specification? ▪ Has the polymer modified asphalt emulsion membrane been sampled and tested? Does it meet the requirements set forth in the Standard Special Provision?

PRE-SEAL INSPECTION RESPONSIBILITIES	
WEATHER REQUIREMENTS	▪ Have air and surface temperatures been checked at the coolest location on the project? ▪ Do air and surface temperatures meet agency requirements? ▪ Is rain expected before or during paving operations? ▪ Are freezing temperatures expected within 24 hours of the completion of any paving runs?
DETERMINING APPLICATION RATES	▪ Agency guidelines and requirements are followed. ▪ Rut filling and leveling course requirements is a separate item and rates have been calculated or estimated to properly re-profile roadway. ▪ Has a full mix design been done? ▪ Are emulsion membrane application rates correct for the pavement surface? ▪ More emulsion may be required on roads with porous surfaces and less for those with flush surfaces or PCC surfaces.
SURFACE PREPARATION	▪ Is the surface clean and dry? Has it been swept? ▪ Have areas with oily residue been scrubbed? ▪ Have all pavement distresses been repaired? ▪ Has the existing surface been inspected for drainage problems? ▪ Have all utilities been raised and masked? ▪ Has project been laid-out to ensure the best possible results?
EQUIPMENT INSPECTIONS	
BROOM	▪ Are the bristles the proper length? ▪ Can the broom be adjusted vertically to avoid excess pressure?
APPLICATION EQUIPMENT	▪ Has the machine been calibrated to accurately spray the correct amount of membrane? ▪ Are all spray tips clean and free of blockage? ▪ Is there a double or triple overlap of spray fan? ▪ Is the paving unit clean and operating correctly? ▪ Are flow gates clear, set at the right height, and functioning properly? ▪ Are conveyors and augers functioning properly? ▪ Is the flow system (manual or automatic) operational? ▪ Are material levels in the auger chamber of the paving unit set correctly? ▪ Do the screed heaters work? ▪ Is the screed clean and properly set? Is the angle of attack correct? ▪ Is the automatic leveling system working and correctly set? ▪ Is the paver speed correct for correct thickness and angle of attack? ▪ Are the screed strike offs clean and providing a uniform mat?

EQUIPMENT INSPECTIONS	
ROLLERS	▪ Are appropriate rollers being used? Do they comply with the requirement set forth in the Standard Special Provisions?
MATERIAL DELIVERY VEHICLE	▪ Do dump trucks or live bottom trailers properly match up with the paving unit?
CALIBRATION OF EQUIPMENT	▪ Are all machines properly calibrated? ▪ Who carried out calibration? ▪ Has documentation has been provided?
PROJECT INSPECTION RESPONSIBILITIES	
TRAFFIC CONTROL	▪ Do the signs and devices used match the traffic control plan? ▪ Does the work zone comply with Caltrans requirements? ▪ Flaggers do not hold the traffic for extended periods of time? ▪ Unsafe conditions, if any, are reported to a supervisor? ▪ Signs are removed or covered when they no longer apply?
EMULSION MEMBRANE APPLICATION	▪ Has the emulsion temperature been checked? ▪ Are high winds expected? Will the expected weather conditions delay the breaking of the emulsion? ▪ Has emulsion application spray bar been checked for blocked nozzles? ▪ Has application rate been checked? ▪ Is the application even and does it cover the entire pavement? ▪ Is the application in accordance with relevant CT guidelines?

PROJECT INSPECTION RESPONSIBILITIES	
LAY DOWN OF BWC GAP GRADED MIX	▪ Has a test strip been successfully laid and compacted? ▪ Is the surface dry (damp is OK)? ▪ Is the mix temperature correct? ▪ Is the paving unit progressing at a uniform speed? ▪ Are the hopper, augers, and screed operating correctly? ▪ Is the screed set at the correct height? ▪ Is the mat being tamped uniformly and is the mat a uniform thickness? ▪ Are height adjustments minimal? ▪ Are height adjustments allowed sufficient times to be effective? ▪ Is the mat uniform looking? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?
ROLLING MIX	▪ Is the surface temperature of the mat correct at beginning of rolling? ▪ Is the roller being operated at the correct speed? ▪ Is the mat uniform looking? ▪ When making transverse joints, are they rolled from the cold side first? ▪ Are longitudinal joints rolled from the hot side first? ▪ Are edge lines and joint overlaps neat and straight? ▪ Is the job stopped if problems persist?
TRUCK OPERATION	▪ Do truck operators avoid driving over mat? ▪ Do truck operators allow the paving unit to push the truck? ▪ Are changeovers of dump trucks smooth, causing no bumping of the paving unit?
LONGITUDINAL JOINTS	▪ Are joints matched properly? ▪ Are joints flat and smooth? ▪ How far does the end gate of the paving unit overlap the previously placed lane (15mm max ($^1/_2$ in))? If not, excess material should be raked off. ▪ Is excessive raking avoided? Minimal raking of the longitudinal joint should be done. ▪ Are longitudinal joints rolled from the hot side of the joint first? ▪ Are the joints straight and compacted? ▪ Ensure no gaps!

PROJECT INSPECTION RESPONSIBILITIES	
TRANSVERSE JOINTS	▪ Transverse joints should be avoided and should be used only at the end of paving or when problems occur in laying. ▪ Is the mat uniform up to the joint? ▪ Is excessive raking avoided when forming the joint? ▪ Is the joint compacted transversely? If there are restrictions, is the joint compacted longitudinally? ▪ Is the joint tight and well compacted and close to invisible?
BROOMING	▪ Does brooming occur shortly before placement of the bonded wearing course?
CLEAN UP	▪ Is all loose mix removed from the traveled way? ▪ Are any spills cleaned up?
OPENING THE MIX TO TRAFFIC	▪ The traffic travels slowly — 40 kph (24 mph) or less—over the fresh mat? ▪ Are reduced speed limit signs used? ▪ Are all construction related signs removed when opening to normal traffic?