BITUMINOUS BINDERS

1. Introduction

The bituminous binder predominantly used in road pavement work is of petroleum origin and is known simply as bitumen. This black, cementitious substance is substantially inert and non-corrosive. Bitumen behaves as a thermoplastic material; on the application of heat it softens gradually and returns to its initial state on cooling. It is produced from the refining of crude petroleum oil and its properties of chemical inertness, water resistance and natural adhesiveness make it an ideal material for a variety of applications. Bitumen has consequently found wide application for such diverse purposes as:

- Paving
- Crack filling
- Waterproof packaging
- Electrical insulation
- Adhesives
- Damp proofing in the building industry
- Timber preservatives

to name but a few.

Confusion can easily arise over the use of terms, for instance, American literature refers to bitumen as “asphalt” or “asphalt cement”. This is a confusing term since elsewhere, including Australia, asphalt is the term used to describe a mixture of bitumen and aggregates which forms a paving material.

Bitumens, on the other hand, have been in use for many years without any evidence from animal tests or human experience that they are associated with long-term detrimental effects in man when used in accordance with current work safety instructions.

Bitumen is a product with a long and safe history of use as a construction material in a wide variety of applications such as asphalt pavements. There have been many studies on exposure to fumes generated from bituminous products during hot applications. Industry experience is that when good working practices are applied, bitumen fumes do not present a health risk to workers.

Independent research by IARC, part of the UN World Health Organisation (WHO), has produced no evidence of a causal link between exposure to bitumen fumes and cancer.

It is particularly important to distinguish between bitumen and coal tar products. Coal tars are produced by destructive cracking of coal based materials and they differ from bitumen in that they contain large amounts of particular types of polycyclic aromatic hydrocarbons (PCAHs) which are known carcinogens.

2. Bitumen

2.1 Origin and History of Bitumen

Natural bitumen is probably the oldest petroleum product to be used by man. The ancient Egyptians used it for embalming mummies and in jewellery thousands of years BC. Through the ages it has been used in the Middle Eastern countries for a variety of water-proofing and construction jobs. King Nebuchadnezzar II (approximately 635–561 BC) is believed to have used naturally-occurring bitumen to waterproof the masonry of his palace and as a grout for stone roads.

The bitumen was obtained from natural seepages out of the ground in various parts of the Middle East, particularly in Persia (or Iran as it is now known). Another natural occurrence of bitumen is the famous lake in Trinidad, which consists of bitumen and solid matter many metres deep. Because of its special properties this bitumen is dug out and sold world-wide as “Lake Asphalt” and is now used mainly for building tanking and waterproofing.

Although naturally occurring bitumens are still available, they account for less than half of one percent of the total bitumen consumption today. In Australia the market of between 500 and 600 thousand tonnes is almost exclusively produced from the refining of crude petroleum oil.

The modern use of bitumen is mainly in road construction for binding and sealing purposes, and this use dates back only to the late 19th century, little more than a hundred years ago.

2.2 Production of Bitumen

Bitumens are produced from suitable crude petroleum oils, essentially by a process of distillation. The crude oils used in bitumen production are selected on the basis of their potential yield and their ability to produce suitable products for a particular application.

Australian crudes are totally unsuitable for making bitumen. They are too light in nature and are too waxy. The correct crudes for bitumen production are the naphthenic or aromatic crudes. Crudes from the Middle East region are of this type and are almost exclusively used in Australia to manufacture bitumen, however, other suitable crudes are found in North and South America, Russia and parts of Central Africa.

Basically all bitumens derive from the material which remains after crude oil has been distilled once at atmospheric pressure and once under vacuum. This material, called “vacuum residue”, is then transformed into the appropriate grade by selection of one or a combination of the following processing options available to the refiner, i.e.:

- It may be taken direct from the vacuum tower as vacuum residue provided that the viscosity is correct.
- It may be blended with other bitumens to obtain the correct viscosity.
- It may be combined with other extracts and refinery products to enhance such properties as its colloidal stability and its thermal/oxidation resistance.
- It may be “blown”, i.e. heated in air to instigate oxidative polymerisation which has the effect of raising its viscosity.

The actual production route chosen will depend on the type of crude being processed, the specification it must meet and the particular product stream and equipment options the refinery has at its disposal.

2.3 Bitumen Characteristics

The characteristics of bitumen which make it most suitable for use in road manufacture are:

- Strong adhesiveness; produces cohesive mixes with stone
- Water resistance
- Flexibility and ductility
- Durability; highly resistant to weathering
- Non-toxicity.

The more important physical properties which characterise a bitumen can be determined in a series of laboratory test procedures. These test methods include a wide range of laboratory techniques. Many of the methods are empirical in nature and it is imperative that they are carried out in strict compliance with the recommended procedures.

Paving grade bitumens are covered by Australian Standard AS2008, “Residual Bitumen for Pavements” and appropriate test methods are specified in Australian Standard AS2341, “Methods of Testing Bitumen and Related Roadmaking Products”.

The properties specified in AS2008 are:

Viscosity at 60ºC (Pascal seconds, Pa.s)

This property indicates the rate of flow of the bitumen at 60ºC.

Viscosity at 135ºC (Pascal seconds, Pa.s)

This property indicates the rate of flow of the bitumen at 135ºC and, in conjunction with the viscosity at 60ºC, gives an indication of the temperature susceptibility of the bitumen.

Penetration at 15ºC (millimetres, mm)

This is a measure of the low temperature hardness of a bitumen and is determined by applying a given weight (200g) to a needle of specific dimensions for a given period of time (60 seconds) at a temperature of 15ºC. The penetration is recorded as the depth in millimetres to which the needle penetrates the bitumen.

Density at 15ºC (kilogram per litre, kg/L)

This will be slightly greater than 1.0 for bitumen, normally 1.02 to 1.04.

Flashpoint (ºC)

Always greater than 250ºC which means that bitumens complying with AS2008 are therefore not classified as flammable or combustible liquids (as specified under Australian Standard AS1940– "The Storage and Handling of Flammable and Combustible Liquids").

Matter insoluble In Toluene

This indicates the purity of the product and a maximum of 1% insoluble matter is specified.

Effect of heat and air (Rolling Thin Film Oven Test)

This test determines the effect of heat and air on a thin film of bitumen when it is heated in an oven at 163ºC for 85 minutes. The amount of hardening is determined by both a ductility test at 15ºC and a viscosity test at 60ºC on the residue obtained from the oven test. The RTFO test is intended to estimate the degree of bitumen hardening which occurs in asphalt production plants.

Durability (days)

Durability is best defined as the ability of bitumen to retain its original characteristics over time.

The Australian durability test was devised by ARRB Transport Research as a method of predicting the rate at which bitumens harden in service. The theory is that oxidative hardening causes embrittlement of the thin bitumen films holding stone in sprayed seals and thin asphalt surfacings, and that this is a major cause of water ingress and stone loss.

This property is usually specified by Western Australia, South Australia, Tasmania and Victoria, but not by New South Wales, Queensland and the Northern Territory road authorities.

2.4 Bitumen Grades

Paving grade bitumens are classified in AS2008 by the mid-point of their specified viscosity range at 60ºC measured in Pascal seconds (Pa.s) as shown:

Formal Grade	Informal Designation	Viscosity Pre – RTFO at 60ºC Pa.s	Viscosity Post- RTFO at 60ºC Pa.s
Class 170	C170	140–200	
Class 240	C240	190–280	
Class 320	C320	260–380	
Class 450	C450		750 – 1150
Class 600	C600	500–700	
Multigrade 500	M500	400 - 600	
Multigrade 1000	M1000		3500 - 6500

AUSTROADS Specification Framework for Polymer Modified Binders (AG:PT/T190) and AUSTROADS Guide to the Selection and Use of Polymer Modified Binders & Multigrade Bitumens (AP-T235/13) cover these products

2.5 Bitumen Modification

Modern roads are required to perform better, last longer and sustain higher axle loadings and traffic densities than they have ever done in the past. As a result, conventional bitumen binders may need to have their properties enhanced for some applications.

The properties of the bitumen can be enhanced by the use of additive to alter or improve its performance. Some of these modifiers are:

(i) Adhesion Agents

The addition of adhesion agents, which are similar in chemistry to cationic emulsifiers, will improve the adhesion or the bitumen to the stone surfaces.

(ii) Asphaltenes

Naturally occurring asphaltenes can be added to stiffen the binder without having to resort to extra air blowing in the manufacturing process.

(iii) Oxidation Inhibitors

These materials are currently under trial as a means of improving the bitumen’s resistance to oxidative hardening in service, however a cost/performance effective product has yet to be proven.

(iv) Rubbers and Polymers

Addition of natural or synthetic rubbers or polymers to bitumen improves its mechanical properties. For instance, an increase in resistance to deformation helps prevent rutting of asphalt and an increase in elastic recovery helps a surface recover from the deforming effects of transient traffic loads. The addition of rubbers and polymers to bitumen is discussed in a later section.

(v) Chemical Modifiers

A number of chemical modifiers are also promoted to modify or correct bitumen characteristics to improve pavement performance Care should be taken to ensure that only proven products are selected for use.

3. Cutback/Fluxed Bitumen

3.1 Introduction

Binder characteristics can also be modified by the addition of light hydrocarbon products known as “fluxes” or “cutters” to bitumen. The most common flux and cutter used are automotive distillate and kerosene respectively.

The purpose of a flux is to permanently reduce the viscosity of bitumen during application and service whilst the purpose of a cutter is to temporarily reduce the viscosity of the bitumen binder during application.

In practice, some lighter fractions of a flux do evaporate from the binder in service and some heavier fractions of cutter remain in the binder after application and curing.

3.2 Cutback/Fluxed Bitumen Production

Cutback/Fluxed bitumens may be produced in the refinery or bitumen depot to Australian Standard specifications or may be blended in the field by adding a suitable flux oil or cutter to the bitumen.

3.3 Cutback/Fluxed Bitumen Characteristics

3.3.1 Fluxed Bitumens

These are in common use for production of warm asphalt mixes and also in bitumen spraying or surface sealing work. The bitumen is fluxed or mixed with a relatively non-volatile petroleum oil, such as Automotive Diesel Fuel. The quantity of flux oil employed is variable up to about 20%, and a figure of 2% to 10% is quite usual. The addition of this flux oil, while obviously softening the bitumen, is considered to keep the bitumen “lively”, i.e. it retards the eventual hardening and cracking of the finished surface. Recent evidence shows, however, that although it is intended that the flux oil remains permanently in the bitumen, this will only occur if heavy fluxes such as furnace oils are used, but even then some evaporation/absorption of the lighter fractions can occur.

3.3.2 Cutback Bitumens or Cutbacks

In contrast to the fluxed bitumens which have relatively non-volatile flux oil, cutbacks comprise of bitumen which has its viscosity reduced by the addition of a relatively volatile material such as kerosene. Low flash cutter is the material normally used in the field, while a product similar to aviation turbine kerosene is commonly used in refinery production.

The purpose of adding a “cutter” is to temporarily lower the bitumen viscosity, either to improve its wetting ability or simply to allow more time for road crews to apply cover aggregate before it hardens fully.

It will be appreciated that the “cutter” (i.e. the material used to reduce the bitumen viscosity), being volatile, will not remain permanently in the bitumen but will eventually be lost, leaving the remaining material similar in hardness to the original bitumen. It must be admitted, however, that there can be a significant retention of kerosene even after prolonged periods.

While most of the cutbacks employed are those containing kerosene type of “cutter”, other “cutters” may be used to ensure that the correct “setting-up” time is achieved.

3.4 Flux/Cutback Bitumen Grades

Cutback bitumens can be classified on the basis of their “setting-up” time into three types as follows:

3.4.1 Rapid Curing (RC) type

As would be expected, these are produced with a motor spirit type cutter and are consequently highly flammable and are not normally used. These have special applications where rapid curing is required.

3.4.2 Medium Curing (MC) type

This is the type mentioned above containing a kerosene type cutter and quite often has a small percentage of flux oil. These are used in sealing work and cold mixes for patching. Australian Standard AS2157, “Cutback Bitumen”, covers medium-curing cutback bitumens for roadmaking purposes (see Appendix 2).

3.4.3 Slow Curing (SC) type

These cutbacks contain a still heavier cutter or flux oil such as Automotive Diesel Fuel and are used in road sealing and warm mixed asphalt.

Note 1: Each of the above types may be manufactured in several viscosity grades, i.e. containing varying amounts of the appropriate diluents.

Note 2: Classification of the above materials under Australian Standard AS1940 “The Storage and Handling of Flammable and Combustible Liquids” should be checked against flashpoints of each individual material being handled, as this will vary depending on the type and amount of cutter present.

4 Bitumen Emulsions

4.1 Introduction

A bitumen emulsion is a bitumen which has been converted to a fine suspension of bitumen droplets in water, usually by means of a high energy shearing device called a “colloid mill”. These droplets are prevented from agglomerating by the action of chemical emulsifiers which cause the surface of the droplets to become charged and hence repel each other.

In emulsified form bitumens can be handled at ordinary temperatures and this eliminates the need for expensive solvents as diluents.

Once in contact with aggregate the emulsion is able to coalesce (set) and the water either runs off or evaporates. By careful control of the emulsion chemistry its rate of coalescence, or setting rate, can be adjusted to be slow, medium or rapid setting in order to have optimum versatility.

4.2 Production of Bitumen Emulsions

The majority of emulsions are manufactured using a colloid mill. The mill consists of a high speed rotor travelling between 1000 and 6000 rpm inside a casing (stator) with a gap of 0.25–0.5 mm between the rotor and the stator.

An emulsifier is made up of water and emulsifying agents, and fed separately but simultaneously with the hot bitumen into the emulsion mill. The temperature of the components is carefully monitored to ensure that the viscosity of the bitumen is low enough to produce a fine dispersion of bitumen particles in the emulsion, however the bitumen temperature must be low enough to ensure that the emulsifier does not boil in the mill.

As the bitumen and emulsifier are forced through the small gap between the rotor and stator the bitumen breaks into small globules which are coated with emulsifier. The emulsifier gives the surface of the bitumen droplets like electrostatic charges which stop the bitumen globules from coalescing. The polarity (anionic or cationic) of the electrostatic charge is determined by the emulsifier used.

4.3 Bitumen Emulsion Characteristics

There are two distinct types of emulsions, classified by the resultant electrical charge on the bitumen particles. One type is called “anionic” and the particle charge is negative. The other type is called “cationic” due to the positive particle charge.

Since most aggregates have a negative net surface charge, anionic emulsions have little or no natural affinity for the stone. Coalescence of anionic emulsions therefore occurs almost exclusively by evaporation of the water from the emulsion.

Cationic emulsions, however, have the correct particle charge to be attracted to the surface of the aggregate, thereby neutralising its surface charge and causing coalescence. This enables a more controllable setting rate and improved adhesion to the aggregate, even if the stone is damp. Consequently, cationic emulsions tend to have more versatility in use than anionic emulsions.

4.4 Bitumen Emulsion Grades

Australian Standard AS1160:-1996 “Bitumen Emulsions for Construction and Maintenance of Pavements” (see Appendix 3) specifies various grades of anionic and cationic bitumen emulsions as follows:

4.3.1 Anionic Rapid Setting (ARS) – Suitable for surface sealing or patching work. It may be used as a tack coat for asphalt work.

4.4.2 Anionic Medium Setting (AMS) – Suitable for specialised enrichment, patching and sealing work.

4.4.3 Anionic Slow Setting (ASS) – An emulsion sufficiently stable for mixing with water for surface enrichment and dust laying. It is also used for soil stabilisation.

4.4.4 Cationic Rapid Setting (CRS) – Has similar application areas as ARS but an added advantage is that it can be used with damp aggregate.

4.4.5 Cationic Medium Setting (CMS) – Suitable for specialised enrichment, patching and sealing work.

4.4.6 Cationic Slow Setting (CSS) – Suitable for similar applications as for ASS. It is particularly suited to soil stabilisation and for incorporation in the slurry sealing process.

4.4.7 Cationic Aggregate Mixing (CAM) – Specially formulated for mixing with aggregate in the preparation of cold mix for patching work. The emulsified bitumen usually contains a cutter or flux oil to permit stockpiling of the cold mix. CAM patching mix has superior performance over fluxed bitumen mixes, as patches made from CAM do not have the same tendency to bleed through the surface layer.

Additionally, higher bitumen content emulsions applied at elevated temperature are being developed to minimise transportation costs and also to allow for the use of large stone sizes in spray seals. Bitumen binders modified with polymers have also been successfully emulsified. In emulsified form the polymers do not suffer from thermal degradation and because of lower application temperatures have a lower risk of burns.

4.5 Selection Of Bitumen Emulsions – Spray Sealing

The selection of bitumen emulsions for spray sealing is dependent on the main purpose for carrying out the works;

(a) To provide a durable skid resistant road surface;
(b) To waterproof the surface of the pavement;
(c) To slow the disintegration of an existing road surface.

The following factors also help determine the grade of bitumen emulsion to be used;

(i) Traffic including weight, number and speed;
(ii) Existing road surface;
(iii) Size and type of aggregate to be used;
(iv) Environmental factors including weather factors, pavement temperature, pavement moisture content.

Emulsion grades and their suitability for spray sealing are listed above in Section. 4

4.6 Selection Of Bitumen Emulsions – Asphalt

Bitumen emulsions can also be used for the manufacture of cold mixes. Cationic Aggregate Mixing (CAM) is specially formulated for mixing with aggregate in the preparation of cold mix for patching work. The emulsified bitumen usually contains a cutter or flux oil to permit stockpiling of the cold mix. CAM patching mix has superior performance over fluxed bitumen mixes, as patches made from CAM do not have the same tendency to bleed through the surface layer.

4.7 Selection Of Bitumen Emulsions -- Crack and Joint Filling

The use of bitumen emulsion is a popular method of crack filling due to the ease of application e.g. watering can. A cationic rapid set emulsion is usually used as it can cope with damp pavements.

Careful assessment of the type/dimensions of the cracks needs to be carried out, as often this method is not cost-effective due to the short life of the repair when used in pavements with active cracking problems. Generally most suitable for small cracks less than 2mm wide with little movement.

Bitumen emulsion modified with natural rubber, or polymers, provides improved performance over standard emulsions. Suitable for small to medium cracks, 2–5mm, with little movement.

5 Polymer Modified Binders (PMBs)

5.1 Introduction

Whilst the majority of roads perform satisfactorily using standard bitumens, increasing traffic demands on the present day road system have outstripped the capacity of standard bituminous binders to cope in some circumstances. Polymer Modified Binders (PMBs) are an option to provide cost-effective prolonged or enhanced pavement performance.

In spray seal and interlayer (membrane) applications, polymers can greatly prolong pavement life by alleviating reflective cracking. In hotmix applications, polymer modified binders are effective in reducing rutting and may also improve fatigue crack resistance. Higher shear resistance can give beneficial effects in roundabouts, tight corners and other high stress areas. In open graded mixes, polymers have demonstrated the ability to prolong life of such overlays by allowing thicker binder films and a tougher film that resists collection of foreign matter and dust in the interconnecting voids, thus maintaining the water drainage function. In combination with a membrane, such mixes are effective treatments for bleeding surfaces. In full depth pavements, polymer modification to increase stiffness of the load-bearing layer can increase pavement fatigue life. Use of polymers can also improve fatigue life in thinner layers.

5.1.1 History of PMBs in Australia

Polymer modified binders began to make an impact on the Australian scene about 30 years ago, although their development began long before that. Extensive studies of binders containing natural and synthetic rubbers were carried out in the UK, for example, in the 1950s and 1960s.

It was not until the advent of the second generation of synthetic polymers, such as styrene butadiene styrene (SBS) block copolymers and ethylene vinyl acetate (EVA) copolymers, that the materials became widely accepted in roading applications. What has helped in their acceptance is the increased requirement for maintenance treatments and the need for improved binder properties to cope with increased traffic stresses on surfacings.

5.1.2 PMB – a very complex material

Bitumen exhibits both viscous (flow) and elastic behavior. At low temperatures or high rates of strain the behaviour is predominantly elastic. As temperature is increased or rate of strain reduced, the behaviour becomes both elastic and viscous. At high temperatures or low rates of strain the behaviour is almost entirely viscous. An important aspect of the behavior of bitumen is that the response changes from mainly elastic to mainly viscous in a uniform manner as temperature increases or strain rate decreases.

The mechanical behaviour of bitumen is complex. The addition of polymers makes it much more so, and the situation is further complicated since different types of polymer modify the behaviour in different ways. The behaviour of some PMBs does not change uniformly with change of test conditions, making selection of the appropriate test apparatus and conditions most important.

In particular, when testing the mechanical properties of PMBs the following variables must be controlled:

- Temperature
- Rate of strain
- Level of strain.

Most present specifications have been developed by producers of the material or have been modified from these by customers such as State Road Authorities. Specifications for PMBs should be performance-based and AUSTROADS has worked toward this objective. A possible disadvantage of the early development of performance-based specifications is that PMB producers will optimise their products to meet the requirements of the specification. Unless the link between specification requirement and field behaviour is very strong, the specification could result in the production of inappropriate materials or retard development of new products.

It is important, when introducing a new PMB based on a novel polymer system, not to attempt to fit the product to existing specifications but to prove its abilities and performance through fundamental data and field experience.

5.2 Production of Polymer Modified Binders

Polymer modified binders are usually produced in static plants using high or medium shear mixers. Some binders can be blended during field operations e.g. crumbed rubber, however increasing quality assurance requirements are leading towards a preference for plant produced PMBs.

High shear plant production is often preferred due to the higher level of fine particle dispersion achievable from this method. This fine dispersion assists the association of the polymer with the base bitumen, allows easier absorption of the maltene fraction into the polymer particles and minimises the propensity for the modifier to settle out during transport and storage.

5.3 Polymer Modified Binder Characteristics

Polymer is a derived word meaning "of many parts". Polymers consist of very large chemical molecules which are, in turn, made up of similar, repeating molecular units. For example, the polymer *polystyrene is* made up of many styrene molecules linked together one after the other. A copolymer has two different sorts of repeating molecular units. Block copolymers have these repeating molecular units in a regularly occurring block pattern. The physical and chemical properties of a polymer will depend on the nature of the individual molecular units, the number of them in each polymer chain and their combination with other molecular types.

Two basic types of polymer applicable to road applications exist. They are:

- Thermoplastic rubbers (Elastomers)
- Thermoplastics (Plastomers)

A thermoplastic rubber is a polymer that has a flexible rubber backbone and large side chains in its structure. SBS (styrene butadiene styrene) and PBD (polybutadiene) are examples of this type.

A thermoplastic polymer is one that will deform in a plastic or viscous manner at melt temperatures. That is, the structure can be reversibly broken down by heat. Such materials are often referred to as plastomers. Examples of such materials are EVA (ethylene vinyl acetate), EMA (ethylene methacrylate) and APP (atactic polypropylene).

STYRENE-BUTADIENE-STYRENE (SBS)

This block copolymer contains styrene molecules which form domains within the binder structure at low temperatures. Styrene molecules from different polymer chains come together in these domains to form a polymeric network structure within the binder. This structure emulates a chemically cross-linked polymer, however it can be reversed by heating until the styrene molecules become more soluble in the bitumen base.

The viscoelastic properties of the SBS-based binders are created by this polymeric network. This polymeric system becomes more fluid at high temperatures due to the breakdown of this network.

As with all polymers, SBS is available in many different forms. The polymer molecules can be different lengths (different number of individual monomer molecules per polymer chain) and can have different arrangements of the molecules (microstructure). These differences can drastically affect the degree of modification provided by a polymer. SBS polymers can have different quantities of styrene relative to the butadiene content (usually expressed as % styrene, and typically around 30%). They can also have different arrangements of the polymer, being either a linear or radial configuration. It therefore follows that two different SBS PMBs may not behave the same, or have the same storage stability, due to differences in the structure of the SBS polymer used, i.e. one 5% SBS PMB may not be the same or as "good" as another 5% SBS. This becomes a problem when PMBs are specified by content of polymer.

SBS based PMBs are usually highly elastic, however the extent is dependent upon the quantity of polymer in the PMB, the type of SBS used and the nature of the bitumen. Usually SBS PMBs require the addition of aromatic and other process oils to improve the "solubility" of the styrene. Too much aromaticity can reduce the effectiveness of the SBS by dissolving the styrene part of the polymer molecules. The elastic properties of SBS PMB are created by the thermally reversible cross-linking of the SBS molecules through association of the polystyrene part of the polymer coupled with the elastic properties of the polybutadiene. Highly elastic properties are not achieved until the SBS content of the PMB is around 5% or greater.

SBS products are reasonably easy to produce by blending powdered SBS polymer into a bitumen/aromatic oil blend using low to medium shear mixing. It is possible for sealing work to use a diluted SBS concentrate. The concentrates are available from some suppliers in the form of blocks or hot, bulk concentrate containing around 15% SBS. Block concentrate is added to a sprayer and blended in by simply circulating the contents. This procedure has quite often been found to be inadequate, with significant quantities of concentrate found in the bottom of sprayers after completion of a spray run. The use of on-site dilution of hot, bulk concentrate or on-site production is now being promoted, however this has the drawback of lack of tight quality control over the properties of the finished product.

The SBS content of SBS PMBs varies considerably depending on the binder properties required for the application. As discussed later, low levels of SBS are typically employed to provide improved aggregate retention properties and in the second coat of a SAM. Higher levels of SBS are typically used in the first coat of two coat SAM applications, in SAMI applications which require very high elasticity, and in asphalt applications.

POLYBUTADIENE (PBD)

As is the case with SBS, a number of types of PBD are available for use in bitumen modification, including some with particular molecular groups in their structure that impart varying characteristics to the modified binder.

ETHYLENE VINYL ACETATE (EVA)

Like SBS, there are many types of EVA polymers available. EVA polymers can contain different ratios of ethylene to vinyl acetate and can have different molecule weights, i.e. different polymer lengths. Typical vinyl acetate levels are 18% and 33%. These polymers are considered to be plastomeric and act by making the PMB stiffer than conventional bitumen. This feature is particularly useful in asphalt applications, where they find most use, however stripping, possibly due to brittle failure of the PMB, has been a problem in seal applications.

EVA polymers are easily blended into bitumen by simple low shear mixing. As with most PMB systems there must be compatibility between the base bitumen and the EVA polymer to ensure optimum properties are achieved. Segregation of the EVA polymer from the PMB can be a problem in storage.

Although EVA finds application in seal work, particularly to provide high shear resistance to aggregate loss, the major application is in asphalt.

CRUMB RUBBER

Crumb rubber (or scrap rubber) is available as a result of the reprocessing of old car and truck tyres. Their effect in bitumen depends on the source of the rubber, the way it was comminuted, its particle size and its content in bitumen. Particular details of the effect of the properties of crumb rubber on the rubber/bitumen blend are contained within various Australian Road Research Board reports.

The crumb rubber consists of either SBR or natural rubber depending on the source. Crumb rubber also contains large quantities of fillers, carbon black and aromatic extender oils amongst other things.

Typically, crumb rubber levels of 5% are used in general seal and reseal work to improve aggregate retention characteristics. Levels of 15% to 20% are used in SAM and SAMI applications.

State Road Authorities are increasingly using this material and governments around Australia and overseas are beginning to specify its use due to the environmental advantages of disposing of the material into usable product rather than into land fill.

Crumb rubber is usually added to the bitumen on site using special mixing apparatus. The on-site blending process can, however, significantly reduce productivity, and a loss of up to 50% has been reported. Other problems associated with the use of crumb rubber include increased pump wear. Also, significantly higher application rates are employed in crumb rubber spray seals.

Other types of polymers have been used to modify bitumen, such as thermosetting epoxy resins which form permanent chemical cross-links by chemical reaction. Rubbers such as neoprene or SBR (styrene butadiene rubber) have also been used. Fully formulated products such as Olexobit are available for specific applications. What these polymer systems have in common is that they all give some degree of viscoelasticity.

5.4 Polymer Modified Binder Grades

5.4.1 PMB Specifications

Specifications covering PMBs were originally published by most state road authorities in Australia. These were developed from suppliers' specifications and typically cover specific polymers and products. The specifications usually rely heavily on test procedures developed for bitumen. Such procedures are not appropriate for the more complex behaviour of PMBs, and in many cases the important variables are either not controlled or not measured.

Ideally, specifications for PMBs should be performance-based and, with this in mind, an AUSTROADS committee including manufacturers and users was set up to develop a more appropriate PMB specification and guidelines.

When looking at the testing of complex materials such as PMBs, it is convenient to split the types of tests used into two categories:

a) Those tests which assist with the evaluation of PMBs for the purpose of understanding their behaviour.

b) Tests which can be used for day-to-day quality control of a particular formulation.

Evaluation tests are likely to involve more sophisticated equipment than quality control tests and are not considered in detail in this document.

Summary of Specification Tests

The most frequently specified tests include:

- Penetration at 25^{0}C
- Viscosity at 60^{0}C
- Viscosity at 135^{0}C
- Softening Point
- Ductility at -5^{0}C to 25^{0}C
- Fraas Point
- Elastic Recovery
- Flash Point.

Commonly specified are:

- Solubility in Trichloroethylene
- Density
- Segregation.

Current Specification Developments

The AUSTROADS/ARRB TR Steering Committee for Polymer Modified Binders developed a performance-based specification which will accommodate current applications. This specification covers PMBs for application where rutting resistance in asphalt is desired, where fatigue resistance in asphalt is required, for crack control applications in both asphalt and sealing products and where improved aggregate retention in seal work is required.

This specification continues to be developed as a better understanding of the relationship of laboratory performance or performance related test procedures to actual field behaviour is established. The specification also needs to ensure that innovative products and blends can be accommodated in the specification structure.

The *AUSTROADS Specification Framework for Polymer Modified Binders* (AG:PT/T190) is the current specification for PMBs. The *AUSTROADS Guide for the Selection and Use of Polymer Modified Binders & Multigrade Bitumens* (AP-T235/13) is also available.

6 Application Binder Selection

6.1 Spray Sealing

The selection of the appropriate binder for spray sealing works is an essential element in ensuring the long term performance of bitumen seals. The preferred binder can only be determined by taking into account the various elements of good spray seal design practice. The details of spray seal design are covered in a further AAPA course but, in general, considerations include;

(a) Nature of treatment, e.g. new seal, reseal, prime, enrichment etc

(b) Pavement condition;

(c) Environmental factors, e.g. pavement temperature;

(d) Aggregate properties;

(e) Availability of products.

6.1.1 Bitumen

The most common bitumen used in spray sealing is Class 170 and Class 320 bitumen may be used when the pavement environment or product availability dictate their use.

6.1.2 Cutback Bitumens

When applying seal coats, it is preferable to tailor the amount of cutter to suit the conditions rather than use the standard sealing grades.

This approach and attention to detail is one of the main reasons behind the generally high standard of sprayed sealing achieved in Australia.

For workability it is often necessary to temporarily reduce the viscosity of the binder in the field. This is achieved by adding a light to medium volatile oil as the cutter. Cutting back is regarded as a temporary effect and the cutter is not regarded as being part of the residual binder.

The quantity of cutter to be added is dependent on the ambient air temperature, traffic volume and the type and size of aggregate used.

The quantity of cutter added varies from 2 to about 20 parts per 100 parts (2-20% by volume) of bitumen, by volume measured at 15 degrees C.

Primers

Primers are cutback bitumens which may be produced as:

– Rapid curing

– Medium curing

– Slow to medium curing.

Only the medium and slow to medium curing cutback primers are commonly used. The rapid curing uses a very volatile cutter, similar to petrol, which makes it less safe to use.

The type of primer normally used is a penetrating slow hardening material of low viscosity and low surface tension. Primers are used to obtain a good interfacial bond between the pavement and the initial bituminous surfacing.

The selection of a primer depends on suitability, availability and economy, in that order. The grade, and rate of application, depends on the type of pavement material, compaction, moisture content, prevailing weather conditions and the life required before the initial bituminous surfacing is applied. The penetrating ability of a primer varies with its viscosity, and this should be such that it will penetrate the surface and be absorbed. Little absorption, or setting-up, should take place before the desired penetration is reached.

Primerbinders

Primerbinders are generally the medium curing cutback bitumens.

Primerbinders were originally developed for use in conditions where there were difficulties using primers, e.g. high traffic volumes, cold and damp weather conditions. The primerbinders normally used are similar in characteristics to the primers but are less penetrating and more viscous, thus leaving a larger proportion of the material on the surface of the pavement to hold and retain covering aggregate.

Similarly to primers, the grade and rate of application also depends on the type of pavement material, compaction, moisture content and prevailing weather conditions, as well as the traffic volume and aggregate size.

Grades of Primers and Primerbinders (cutback bitumen)

The grades produced fall into three main categories:

Australian Standard Grades – these are divided into grades based on viscosity.

Proprietary Grades – also divided based on viscosity, but using refinery residues and/or different cutters to the standard grades, they may or may not comply with the Australian Standard.

Field Produced Grades – produced in the field by mixing Class 170 bitumen, flux oil and cutter to produce grades which are broadly equivalent in performance to the above.

As a guide, primers and primerbinders are divided into the various grades based on viscosity as follows:

Grades of primers and primerbinders

	Grade	Viscosity Range Pa.s. at 60 degrees C
Primer		
	Very light	0.010–0.020
	Light	0.025–0.050
	Medium	0.050–0.080
	Heavy	0.080–0.200
	Very Heavy	0.200–0.400
Primerbinder		
	Light – Medium	1.0–3.0
	Heavy	4.0–7.0

Setting Up

Primers and primerbinders set-up, i.e. they thicken and increase in viscosity, by three processes:

- Reduction in temperature
- Loss of the light oils by evaporation
- Selective absorption of the oils by the fines in the pavement material.

6.1.3 Bitumen Emulsions

The selection of bitumen emulsions for spray sealing is dependent on the main purpose for carrying out the works;

(d) To provide a durable skid resistant road surface;
(e) To waterproof the surface of the pavement;
(f) To slow the disintegration of an existing road surface.

The following factors also help determine the grade of bitumen emulsion to be used;

(v) Traffic including weight, number and speed;
(vi) Existing road surface;
(vii) Size and type of aggregate to be used;
(viii) Environmental factors including weather factors, pavement temperature, pavement moisture content.

Emulsion grades and their suitability for spray sealing are listed above in Section. 4.4

6.1.4 Polymer Modified Binders

Polymers may enhance seal performance by:

- Improving aggregate retention by an increase in cohesion of the binder.
- Minimising, delaying or inhibiting reflective cracking through improved elastic properties.
- Minimising bleeding by increasing service viscosity and increasing penetration index.
- Improving shear resistance on bends and other high stress areas.
- Improving water-proofing by increasing cohesion and water resistance.

The most important application areas are HSS (high stress seals), XSS (extreme stress seals), SAM (strain alleviating membranes) and SAMI (strain alleviating membrane interlayers).

HSS – The use of PMBs in new seals is normally only required in special circumstances, for example, for pavements subject to shrinkage cracking or for pavements subject to high shear (high turning, cornering or other shear effects). Various PMB types are used for this application and are listed in "*The AUSTROADS Specification Framework for Polymer Modified Binders* (AG:PT/T190)".

XSS – the XSS seal has been developed to cope with large volumes of traffic, particularly with high percentages of heavy vehicles. These are double/double seals consisting of a medium level PMB in both layers. Further guidance on the use of XSS seals is given in the Austroads Guide to the Selection and Use of Polymer Modified Binders & Multigrade Bitumens (AP-T235/13).

SAM – A Strain Alleviating Membrane (SAM) is a membrane consisting of an application of a suitable PMB and stone (usually 10 to 14 mm nominal top size). Application may also be as a multiple double/double coat seal. SAMs are mostly applied over:

- Structurally inadequate pavements.
- Marginal pavements.
- Cracked but sound pavements.
- Bridge decks.

In general, double coat seals with a high percentage of polymer in the first coat have been found to work best. Localised pavement failures should be rectified first.

The selection of the PMB for SAM application will depend on the seal and its function. Recommended product specifications are listed in *"The AUSTROADS Specification Framework for Polymer Modified Binders (AG:PT/T190)".*

A Strain Alleviating Membrane is required to attenuate strains at the tip of cracks and therefore reduce or prevent the occurrence of crack propagation. This may be achieved by storage of the strain and then release over time (delayed elastic behaviour) or by stress or strain relaxation. Either technique is effective, as long as the membrane retains its structural integrity and does not flow into the crack.

The absorption of stress or the alleviation of strain is as much a bulk effect as a material property, thus the higher the binder application rate the better. Usually a SAM is required to fill the existing surface texture plus about two thirds of the void space. The binder's higher viscosity and elasticity relative to bitumen affects the ability of the aggregate to reorientate to their flattest position. Therefore extra binder may be required depending on the seal. Bleeding at these higher binder application rates is reduced by the higher viscosities and softening points of the polymer modified binders.

SAMI – A Strain Alleviating Membrane Interlayer (SAMI) is a membrane of polymer modified binder such as crumb rubber or SBS with a single application of 10 to 14 mm stone. SAMIs are mostly applied over cracked pavements or to water-proof bridge decks. They are designed to alleviate tensile strains that may otherwise be transmitted to a new overlay and should only be trafficked for a few days before placement of the asphalt overlay.

The aim of a SAMI is similar to a SAM that is to attenuate strains at the tip of cracks and thus reduce or prevent crack propagation. A SAMI is designed to create an integral membrane between a cracked base layer and an asphalt overlay. They are usually designed to fill 90% of the available void space in the aggregate. The aggregate is required only to provide a platform for traffic until the asphalt overlay is placed. The high viscosity and softening points of the polymer modified binders prevents bleeding. Recommended product specifications are listed in "The *AUSTROADS Specification Framework for Polymer Modified Binders (AG:PT/T190)"*.

General Seals/Reseals – A common practice is to add small quantities of a polymer such as SBS or PBD to provide improved aggregate retention. Polymer content of 1% to 3% is most commonly used however, at this level, the polymer is not providing the high elastic properties that are exhibited in SE grade PMBs.

Crumb rubber at about 5% is also commonly used. A strong Government lobby is pushing for increased use of crumb rubber in road works on environmental grounds, however the prime factor for its use should be improved pavement performance, as there are other cost-effective ways of using recycled rubber.

6.2 Asphalt

6.2.1 Introduction

In asphalt, bitumen is a binder (or glue). Its role is to hold aggregate particles together and to provide waterproofing of the pavement. It is present as a thin surface film between aggregate particles. In rheological terms, bitumens are viscoelastic liquids. This viscoelasticity results from behaviour which combines "fluid-like" viscous characteristics and "solid-like" elastic characteristics depending on the deformation or loading time.

At the high temperatures involved in asphalt mixing, e.g. 150ºC or greater, bitumens tend to exhibit Newtonian behaviour, in that the rate of shear is directly proportional to the applied shearing stress. At pavement service temperatures, both temperature and loading rate are important factors contributing to linear viscoelastic behaviour.

The preparation of asphalt, or more particularly hot mix, involves the heating and drying of aggregate followed by coating by hot bitumen in a pugmill or drum mixer. Mix temperature must be carefully controlled so as to prevent excessive hardening of the bitumen due to oxidation at high temperatures. This is offset by the need to maintain a certain minimum mix temperature to ensure adequate spreading and compaction is possible at the application site.

Alternatively, coldmix is prepared by mixing fluxed bitumen or bitumen emulsion (e.g. CAM) with aggregate in a pugmill at relatively low temperatures. This material is predominantly used for pothole patching.

6.2.2 Mix Design Considerations

At typical pavement surface temperatures, the stiffness of the bituminous binder is a major contributor to the stiffness of the asphalt, being dependent on bitumen class, temperature and load duration (i.e. traffic speed).

The effects of these factors are illustrated in the Austroads Guide to Pavement Technology Part 4B *Asphalt*, (Austroads, 2014)

It is important, therefore, to choose the bituminous binder carefully to obtain the desired asphalt properties. Having chosen the bitumen type it is then necessary to determine its optimum content in the asphalt mix. This is dependent on the aggregate and grading, the extent of mix compaction and temperature in service. The optimum bitumen content is determined by laboratory testing, preferably using the same aggregate and bitumen intended to be used in the job mix.

6.2.3 Bitumen

As the binder is responsible for the visco-elastic behaviour of asphalt mixes, the grade of bitumen to be used is an important design consideration.

The grades of bitumen used in asphalt are Class 170, Class 320, Class 600 and Multigrade. The most commonly used grades are Class 170 and 320, whilst Class 600, M1000 and AR 450 in NSW are used mainly in heavy duty pavements.

6.2.4 Cutback Bitumens

Flux/Cutback bitumens can be used in the manufacture of cold asphalt mixes. These mixes are primarily used for road patching and bridge deck pavement maintenance when the use of hotmix is uneconomic due to the quantity required, or the distance of the job site from a mixing plant.

6.2.5 Bitumen Emulsions

Bitumen emulsions can also be used for the manufacture of cold mixes. Cationic Aggregate Mixing (CAM) is specially formulated for mixing with aggregate in the preparation of cold mix for patching work. The emulsified bitumen usually contains a cutter or flux oil to permit stockpiling of the cold mix. CAM patching mix has superior performance over fluxed bitumen mixes, as patches made from CAM do not have the same tendency to bleed through the surface layer.

6.2.6 Polymer Modified Binders

Polymers can be incorporated into asphalt in several ways, usually as a pre-blended polymer modified binder, or as a polymer added direct to the asphalt plant pug mill.

Asphalt performance is affected by the properties of the total mix, not by any single component. It follows that the benefits of using a PMB depend on the total pavement design, layer thicknesses and the location of the PMB layer in the pavement structure.

PMBs in asphalt can provide improved crack control, rutting and shoving resistance, fatigue resistance, aggregate retention and resistance to high traffic stresses.

Crack Control – Placement of an overlay over a deflecting base requires resistance to crack initiation. Binder properties such as elasticity, brittleness, resistance to ageing, fracture toughness and cohesion are important.

Rutting and Shoving – The permanent deformation of a pavement by rutting or shoving is due to a build-up of irrecoverable strains induced by compressive and shearing forces. Deformation usually occurs in the surface layers (top 60mm) of a pavement. Binder properties such as stiffness, viscosity, temperature susceptibility and elasticity are important, more so at high pavement temperatures. Rutting can be considered to be a build-up of deformation by repetitive loading and increased elastic recovery should therefore offset it. Theoretically, rutting resistance is proportional to stiffness and elasticity.

Fatigue Resistance – The loss in load bearing capacity (or modulus) with repetitive loading is caused by fatigue failure of the binder. Binder properties such as elasticity (elastic recovery between loadings allows the binder structure to recover), toughness (the ability to absorb energy without fracture) and stiffness. In thick asphalt layers fatigue strength increases with stiffness. In thin layers flexibility is more important.

Aggregate Retention – Asphalt mixes must retain aggregate in their surface layers to remain effective. Binder properties such as elasticity, toughness, adhesion and cohesion are important.

Resistance to High Traffic Stresses – The resistance to tearing or failure due to single traffic incidents is dependent on the thermal susceptibility, cohesion, adhesion and stiffness properties of the binder.

Recommended product specifications for asphalt binders are listed in “The *AUSTROADS Specification Framework for Polymer Modified Binders (AG:PT/T190)”.*

6.3 Crack and Joint Filling

6.3.1 Introduction

Pavement cracking may occur as the result of a wide variety of causes, but regardless of the cause, the outcome is a path for the entry of moisture. Unless treated, this will result in the accelerated deterioration of the pavement. Treatment will stop or slow down the rate of deterioration and improve the effectiveness of subsequent surfacing treatments.

6.3.2 Crack Characteristics

Pavement cracking can be broadly separated into two major types;

Traffic-induced by vehicles passing over the pavement;

Environment-induced due to temperature variations of the pavement or moisture variations in the sub base material.

In assessing the most cost-effective treatment, consideration needs to be given to the number and dimensions of the cracks and the speed at which the cracks open and close. Environmental crack opening and closing may take place over many hours, whilst traffic-induced crack movement is virtually instantaneous when the axle passes over the pavement crack.

AAPA Pavement Work Tip No 8 “**Treatment of Cracks in Flexible Pavements**“ is a good guide to crack assessment and work practices and is included as an attachment to these course notes.

6.3.3 Bitumen

Hot applied Class 170 bitumen has been found to be a cost-effective treatment for some crack sealing applications, however the need to apply them hot has some handling and safety difficulties which need to be carefully considered when choosing this material. The sides of the crack may need to be primed to ensure adhesion of the bitumen.

6.3.4 Cutback Bitumens

Cutback bitumens have the advantage of cold application, good crack penetration and their use removes the need for crack priming, however there needs to be an escape route for the evaporation of the cutter from the filled crack.

6.3.5 Bitumen Emulsions

The use of bitumen emulsion is a popular method of crack filling due to the ease of application e.g. watering can. A cationic rapid set emulsion is usually used as it can cope with damp pavements.

Careful assessment of the type/dimensions of the cracks needs to be carried out, as often this method is not cost-effective due to the short life of the repair when used in pavements with active cracking problems. Generally most suitable for small cracks less than 2mm wide with little movement.

Bitumen emulsion modified with natural rubber, or polymers, provides improved performance over standard emulsions. Suitable for small to medium cracks, 2–5mm, with little movement.

6.3.6 Polymer Modified Binders

The widths of the cracks and amount/cause of any movement influence the choice of a suitable polymer modified binder. The movement is usually defined in terms of being due to environmental causes or traffic (load) induced. If movement exceeds about 0.5 to 1mm, it is doubtful that a PMB alone will provide a long term solution and it should be used in conjunction with a geotextile.

Hot poured modified bitumen, usually with high polymer content, is generally used as a sealant in overbanding, and routing and filling treatments. These treatments are suitable for medium to large cracks, about 5–15mm with larger movement.

Recommended product specifications are listed in the AUSTROADS AG:PT/T190 and AP-T235/13.

REFERENCES

1. AAPA Asphalt Terms. Information Booklet IB-2. September 1985
2. AAPA Pavement Work Tip No 8 “Treatment of Cracks in Flexible Pavements”.
3. Australian Standard AS2008 - 2013, “Bitumen for Pavements”
4. Australian / NZ Standard AS2341, “Methods of Testing Bitumen and Related Roadmaking Products"
5. Australian Standard AS1160: 1996 “Bitumen Emulsions for Construction and Maintenance of Pavements”
6. CONCAWE Report No 7/82 “Health Aspects of Bitumens”. Den Haag, July 1972
7. Austroads AGPT04B/14 : Guide to Pavement Technology - Part 4B: Asphalt
8. Austroads Specification Framework for Polymer Modified Binders (AG:PT/T190), Sydney 2014.
9. Austroads Guide to the Selection and Use of Polymer Modified Binders & Multigrade Bitumens (AP-T235/13), Sydney 2013.
10. The Shell Bitumen Handbook, Shell Bitumen UK.

11. Bitumen Emulsions, SMEF, 1991

12. Sprayed Sealing Selection & Design, AAPA, 2007