1. INTRODUCTION

1.1. Background

The idea of adding rubber, whether natural or synthetic, to bitumen is admittedly no novelty. However, in most cases the addition process was carried out by hand, by hit or miss methods, without taking account of quantities, possible reactions and the quality standard of the ingredients and the finished product.

It was only in the late sixties that a start was made with the use in the US, especially in Arizona, of rubber powders which had been scientifically mixed with various grades of bitumen.

The inventors of this industrial procedure were Donald L. Nielsen and James R. Bagley, who, developing ideas originally proposed by Charles H. McDonald, had experimented for several years by adding various quantities of rubber powder recycled from ground-up tyres to fluxed bitumen.
Grain size, the proportion of natural to synthetic rubber and the recovery method would vary.

The prime concern was to repair roads in the US with underdimensioned foundations. Deteriorated pavements suffering alligator cracking were covered with a thin film of rubber bitumen binder and chipped with locally available aggregate. Such dressings prevented the reflection of the cracks on the surface of the road. The new elastic membrane just under the surface also provided a waterproof layer which was ideal for applying a thin overlay, which could either be a draining or a dense mix.

Towards the end of the seventies in Europe, and particularly in Belgium, considerable interest was shown in this new binder. In Belgium, both public authorities and roadworks contractors wanted to try out the draining mixes which had already been under test in various countries for several years. After the first successful applications carried out in association with the Centre de Recherches Routières in 1979, Esso Belgium wished to go further and extend the procedure to the motorways. It was only the use of an exceptional binder that made it possible to realize thin layers (25 mm) on test sections on the most densely trafficked motorways. It was with this in mind that Esso Belgium decided in 1981 to sign a licensee agreement for all Europe with Union Oil of California in order to give it rapid access to the latter's technology in this field.
1.2. Components

Rubber bitumen binder contains three components: bitumen, oil and rubber fraction.

1.2.1. Bitumen

The quality of the bitumen is chosen in relation to the application and the qualities required of the finished product. This makes it possible to vary the degree of penetration of the binder from 50 to 200 10/mm. What is much more important though, is the crude oil chosen for the production of the bitumen.

We have found that for bitumens with the same penetration, but formulated using two different mixtures of crude oils, can after reaction with identical qualities and quantities of oil and rubber give rise to finished products with softening points (Ring and Ball test) which differ by as much as 15°C. This implies that our sub-licensees, the actual producers of the rubber bitumen binders, must work carefully when choosing their bitumen.

A preliminary study is thus essential and in some cases a more distant and consequently more expensive source must be sought.
1.2.2. Oil

Use is made of aromatic oils with a very high flash-point produced by the Esso Group. This component, which is fluxed with the bitumen fraction, ensures that the reaction with the rubber continues, which does not occur when pure bitumen is used. The elastomers which are formed in this way give the finished product the desired cohesive and adhesive properties, and which we will return to further below.

1.2.3. Rubber

The rubber fraction consists to a large extent of recycled material obtained by grinding up old tyres from cars and commercial vehicles. The quality requirements for this recovered rubber powder are expressed in terms of:
- chemical composition
- morphology
- grain distribution.

By chemical composition is understood the vulcanized or non-vulcanized condition of the rubber particles and the ratio of natural to synthetic rubber.
The morphology specification refers primarily to differences in specific area of the rubber particles, which by and large depends on the production method. For example when cryogenic grinding is employed, involving immersion in liquid nitrogen (-100°C) a completely different specific area is obtained than when grinding at ambient temperatures.

By grain distribution or sieving is meant the distribution of various particle sizes between specified limits. In doing this adequate attention must be paid to the purity of the recovered materials. Particularly important is the absence of textile and steel waste in the used tyres.

Mixing these components in widely differing proportions, heating and reacting them will result in a binder which can be used in a very wide variety of areas in road construction, industry and waterproofing of engineering structures.

The remainder of this article will concentrate on road construction applications in particular for Draining Mixes using Rubber Bitumen. This construction method has undoubtedly been extremely successful and in recent years has been widely used in most European countries. As the "Pavements" group of the CPTR in France (Comité de Prospective des Techniques de la Route) puts it: "The development of draining mixes will probably be the only noteworthy improvement in road construction in the nineties which road users are likely to remember".
1.3. Applications in Road Construction

1.3.1. SAM (Stress Absorbing Membrane)

The purpose of this application is, as the name suggests, the provision of a membrane which can cushion the effects of stress. Cracks, which are usually the result of under-dimensioning and thermal effects, are overlaid with a thick film of elastic binder. The SAM is applied as a strong layer at rates of 2 to more than 3 kg per m², at temperatures of 200°C, and is then chipped with a layer of aggregate, the thickness of which (15 - 20 kg per m²) will depend on the amount of binder employed.

1.3.2. SAMI (Stress Absorbing Membrane Interlayer)

When a SAM is to be used as an intermediate layer between the existing pavement and a new wearing course (dressing, dense or draining mix) it is known as a SAMI. Like a SAM, this membrane can be applied to both concrete and asphalt pavements. SAMIs can play a valuable role, particularly where draining mixes are to be applied and prevent water and road salt penetrating the underlying courses.
1.3.3. Double Surface Dressings

A combination of the above two applications combined with suitable, and differing, aggregate sizes offers a good solution when waterproofing old pavements. This also ensures excellent skid resistance.

1.3.4. Draining mixes

This application - already tested on a limited scale in the past - is, as a result of the application of modified binders and rubber bitumen in particular, one of the most striking innovations in road constructions in recent years.

In view of the importance of this procedure and its many advantages, we will be returning to it in the following chapters.

1.3.5. Dense mixes

Dense mixes made with rubber bitumen are distinguished from conventional dense mixes by their higher binder content. The good wheel-tracking properties of the mix and the excellent resistance to ageing of the binder have led them to being widely used in the United States. As yet it has been employed only on relatively minor projects in Belgium and France.
1.3.6. **Sealant and filler**

In the United States rubber bitumen mixtures have been widely used as a "crack filler" and as a joint sealant. Various countries in Southern Europe and the Middle East with climates comparable to that of the Southern states of the US also make use of the product.

1.3.7. **Sealing membranes for bridge decks**

Widely varying temperatures generate thermal stresses and cracking in road bridge decks. In time this results in rain and thaw water laden with salt seeping into the metal structure or reinforcing steel of the structure. A rubber bitumen membrane (alone or accompanied by a geotextile) is an excellent material for making this waterproof layer. A membrane of this kind stands up better to extreme temperatures. It is highly elastic even at low temperatures and can be so formulated that it has a high softening point (Ring and Ball test) so that it continues to perform well even in hot summer conditions.
2. DRAINING MIXES

2.1. General

A draining mix, sometimes referred to as highly porous bitumen concrete, is a bituminous mix composed of conventional materials, namely aggregate, sand, filler and a binder.

Draining Mixes are distinguished from dense (or non-porous) mixes by their high voids ratio, namely 20% compared to 4%. This high voids ratio, which is the result of employing a large proportion of rough aggregate (more than 80% of 7/14 grade) ensures that the cavities in the bitumen mix are all interconnected.

The quality of the aggregate is of great importance.

Belgium's Ministry of Works consequently recommends the following values:

- grain form index : $\geq 0.390$
- polished stone value (PSV) : at least 50
- Micro-Deval coefficient of the 10/14 fraction measured in water (MDW) : max. 10
- Los Angeles coefficient (LA) measured on the 10/14 fraction : max. 15
2.2. Benefits

2.2.1. Draining Capacity

The permeability of a draining mix and the rapid draining of the greater part of the rainwater provides a number of significant benefits from the point of view of road safety and driver comfort:
- skid hazards at normal speeds and during braking are significantly reduced thanks to improved grip.
- the danger of aquaplaning at high speed is avoided.
- "wheelspray curtains" are eliminated, thus improving visibility particularly when overtaking commercial vehicles.
- reduction of reflected light and mirror effects, even on dry roads.
- fuel consumption is reduced, particularly on wet roads (a heavy goods vehicle travelling at normal speeds on a road covered with a film of water 1 mm deep throws up 360 litres of water per minute per tyre).

2.2.2. Reduced Traffic Noise

Numerous measurements carried out both in Belgium and other European countries have demonstrated that draining mixes significantly reduce traffic noise.
This reduction is about 3dB(A) for speeds of between 50 to 60 km per hour compared to dense mixes. When compared to grooved cement concrete at speeds of approximately 100 km per hour the measured difference can be as much as 10 dB(A).

For those not familiar with acoustic measurements may we point out that a reduction of 3 dB(A) corresponds to a 50% reduction in sound power (acoustic energy) while a fall of 10 dB(A) represents reduction in sound energy of no less than 90%.

One of the most widely used alternatives for reducing road noise nuisance are sound screens and walls. If they can be installed, which is not always possible, they are nevertheless an expensive solution. A steel or concrete acoustic barrier built to a height of three metres on both sides of the road costs between Bf 24,000 and 30,000 per running metre. A 4 cm thick overlay in draining mix over a waterproof membrane costs per Bf 10,000 to Bf 14,000 per running metre depending on whether there are 2 or 3 lanes in both directions.

Furthermore even after the construction of the acoustic barriers repairs will still have to be made to the existing pavement.
2.2.3. **No rut formation**

The choice of mineral components is extremely important. For this reason aggregates should be chosen with a relatively favourable PSV and which offer satisfactory roughness throughout the lifetime of the pavement. They should also have good impact resistance in order to prevent them being crushed. This is important as this would otherwise result in a reduction of voids and a further compaction of the wearing course.

Once well compacted a draining mix with a good stone skeleton will therefore resist further distortion. Even if some slight physical rutting should occur the motorist will never be troubled by it as no water will remain standing on the road surface.

2.3. **Specific benefits of rubber bitumen**

2.3.1. **High binder content**

One object which many countries strive to achieve is to extend service life by using as much binder as possible in the draining mix. This is one of the greatest of all of rubber bitumen's advantages.
Between 6.5 and 7% of binder can be added to the aggregate without it dripping off. This ensures that the mix has improved cohesion and greater durability. The higher binder content in effect means that the film of binder around the aggregate is thicker while conserving a sufficiently high percentage of voids. Despite the markedly higher quantity of binder (as much as 40% more than with ordinary bitumen) we have observed no binder flushing even after prolonged periods of time and after exposure to higher temperatures, indeed it has been found that these binders have a better dynamic modulus at 30°C (fig. 1).

2.3.2. Flexibility at Low Temperatures

Whereas an ordinary binder become hard and brittle as soon as the temperature falls to a few degrees above freezing point, rubber bitumen retains good elasticity and adhesion. As a result the mix can continue to bear high loads even at temperatures well below freezing.

2.3.3. Improved resistance to fatigue and stress

Laboratory trials have shown that a draining mix prepared with 7% rubber bitumen can withstand many more stress cycles than a conventional draining mix using 5% ordinary bitumen.
The fatigue resistance of a draining mix made with rubber bitumen is comparable to that of dense bitumen concrete. The service life which can be expected of a draining mix made with rubber bitumen is consequently 4 to 5 times longer than with ordinary bitumen (fig. 3).

Esso's European Research Centre at Mont-Saint-Aignan in France has made a systematic study of rubber bitumen mixes with 20% voids and a binder content of 7%. Figures 1, 2 and 3 show the results for the dynamic modulus, dynamic flow (rutting) and intrinsic fatigue.
2.3.4. Improved resistance of the binder to oxidization and ageing

A further advantage of the use of recycled rubber is that the mix contains the anti-oxidants and anti-UV additives of the original rubber. Tests in the US on binders made both with and without rubber have shown that after 13 years the viscosity of a bitumen without rubber increased to values of up to 20 times its original value, while the viscosity of a rubber bitumen was still comparable to that of the original product.

2.3.5. Ecological aspects

Every year 40,000 tonnes of rubber tyres are used in Belgium alone. After losing about 10% due to wear and tear the same quantity finds its way to public dumps. About half the weight of these tyres is reusable rubber. One hundred tonnes of binder, or roughly one kilometer of three-lane motorway, uses about 2500 recycled car tyres or 400 commercial vehicle tyres, simultaneously improving the safety and comfort of the road user and reducing the burden on the environment.
2.4. Performance in winter

The winter performance of draining mixes has given rise to a certain amount of discussion. What is quite certain is that these mixes react differently to de-icing measures than conventional road surfaces. If the services concerned modify their salting schedules to take account of the nature of the pavement, which does not entail the use of greatly increased amounts of salt, open mixes are turn out to be safer. The prime precaution is to ensure that a salt solution remains in the voids when frost and rain are expected. Similarly, observations that the road surface remains dark longer in snow and/or the snow remains longer on the road or otherwise are contradictory. The difference in snow covering has, however, never given rise to any serious difficulties to road users.

2.5. Areas of application

The use of draining mixes is not limited to any specific application. They have been successfully used on motorways (road safety), on by-passes and orbital roads around urban centres (reduction of traffic noise), in built-up areas at traffic speeds of between 50 and 70 km per hour, in tunnels (evacuation of invasive ground water, reflected traffic noise from walls at tunnel entrances and exits), and for airfields (standing water with low cross fall).
2.6. **Use in other European countries**

In the last five or so years applications making use of draining mixes and SAM(I) based on rubber bitumen have been successfully tried in several European countries. In order to acquaint readers of this article with these applications, we give the following list of names under which the technology is used:

- **Germany and Austria**
  - Flüsterasphalt and Elastosam

- **France**
  - Drainochape, Flexochape and Microchape

- **Hungary**
  - Suttogo Asphalt and SAM(I)

- **Italy**
  - Asphalto Silenzioso

- **The Netherlands**
  - Poro Elastisch Asfalt Beton and SAMI

- **Switzerland**
  - Ralastan 100, 200, 300, 500
3. CONCLUSIONS

Draining mixes made with rubber bitumen have demonstrated their worth at the various sites where they have been applied since 1981. Their performance and the maintenance of their characteristics and benefits in time demonstrates that this technology can be used on a wider scale in the future. Application in relatively thin courses (4 to 5 cm) and at high rates (more than 500 m of motorway per day) makes it an ideal renovation technique.

At all places where it is sought to achieve the following:

- reduction of traffic noise
- reduction of aquaplaning hazards
- reduction of spray
- improvement of skid resistance
- profile correction and improvement of evenness

in other words, draining mixes can be recommended for all places where a marked improvement in traffic safety, driver comfort, and quality of life of frontager is necessary or desirable.

And remember, draining mixes with rubber bitumen last and last.

Hugo Van de Velde
Asphalt Sales Engineer
"The Use of Rubber Bitumen in Road Construction (Draining Mixes):" by Hugo Van de Velde, Asphalt Sales Engineer, S.A. Esso, Belgium. Presented by Jacques G. Bardet.

Question/Doug Miller, Medina County, Ohio:

You showed a graph there earlier (effects of temperature on a straight AC20 mix and the rubberized asphalt). The AC in the rubberized asphalt mix, was that an AC20?

Jacques:

No, but we compare with AC20 because the rubberized asphalt has the same penetration as an AC20. It is better to compare a rubberized asphalt with a pure asphalt of the same grade rather than with the starting asphalt grade.

Doug Miller:

I would like to follow-up. Most of the graphs and reports were done with AC20 against and AC20 rubberized mix, and an AC5 against an AC5 rubberized mix. We had a speaker here earlier that said in a lot of areas, you should go from an AC20 mix to a rubberized mix using an AC10 or an AC5 depending on the area. Did I mistake a lot of these graphs or should we not, for a correct comparison, compare between a straight AC20 mix and the rubberized mix we would be using, that comprised of an AC10 or AC5 liquid. It seems like a lot of technical reports were AC20 against AC20 rubberized.

Jacques:

The comparison made in the graph is also true with polymer modified asphalts. Let us take that example of polymer modified asphalts. You will start perhaps with an AC10, an AC5 even, plus some polymer, and you will get a viscosity or penetration in the range of AC20, or AC30 or even an AC40.

Consequently, it does not mean anything to compare to an AC5 even though you start with an AC5 because we know that an AC5 will have a good cracking resistance but not a good rutting resistance, and we don’t need to check that again.

Question/John Corcoran, Manhole Adjusting

Two questions. What is the maximum thickness that you have laid this open graded course? Have you experienced any
problems with raveling or debonding of the aggregate especially going through winter months over a period of time.

Jacques:

We started at one-inch, then we went to two-inches, and so far, after a lot of highways, we like 1.6 inches. It is a good compromise between the cost and the draining capacity. Also, if the layer is thinner than 1.6-inch, you could get delamination of big pieces.

John Corcoran:

How about any ravelling?

Jacques:

Nothing, it is perfect!

Question/Bill Maupin, Virginia Transportation Research:

I have two questions/what were the construction temperatures that you used. What was the mix temperature that you used in the field?

Jacques:

The mix temperature in the field is 180°C (350-360°F), but you can lay down even a 160°C without a problem.

John Corcoran:

Do you have any trouble with drainage in trucks?

Jacques:

Not at all!

John Corcoran:

What type of seal do you use underneath the drainage course. Does that have Asphalt-Rubber in it?

Jacques:

Oh yes! It is the same binder that you are going to prepare for the draining mix. You will use exactly the same one to waterproof your road by spraying a layer of this rubberized asphalt.
Rudy Jimenez, Arizona:

The question is not only for you but for the rest of the presenters talking about drainage mixtures. If pavements have been asked to "breathe" to let the water from underneath go through it as a vapor, then with this impermeable membrane, you will be collecting moisture in the pavement below your membrane. It will just cause stripping.

Jacques:

It's impossible to find a road without any cracks and we don't want to see the rain going through the cracks. I think it would be worse, than the moisture coming from underneath. A conventional resurfacing will seal as well the moisture from below.

Clint Solberg, Wisconsin DOT:

What type of accident reduction have you achieved by using this mix?

Jacques:

I just have one point which is from the French Highway North of Paris. There was a 35% reduction.

Tim Baker:

Has this mixture, the open graded mixture been used in our freeze-thaw cycle climates? Significantly freeze-thaw climates.

Jacques:

Yes, it has been used in Germany, East of France, Austria where the temperature is often around 32°C during the winter, and always going above or below, and in this part of Europe we have much experience with draining mixes.
August 12, 1988

Dear Don,

I received your letters dated July 25 and August 2, 1988.

Enclosed you will find the Belgian specifications for the "rubberized" binder to be used in our Open Graded Surface Courses:

- Penetration 0.1 mm : 60/100
- Softening point : min. 55°C - 15°C
- Fraass Breaking point : max. - 15°C
- Viscosity at 205°C - 60°C : 300 to 1,300 mPa.s.
- Ductility at 5°C - 2°C : min. 7 cm
- Elastic Resilience at 25°C - 2°C : min. 40 %

In France, different binders have been used and up till now, no general specification has been set-up. Beugnet however is respecting following specifications for the "Drainochape" binder:

- Penetration 0.1 mm : 60/100
- Softening point : min. 60°C - 40°C
- Penetration Index : + 1.5
- Viscosity at 205°C - 60°C : 1,000 to 1,700 mPa.s.

Austria has no national specification and CT Bitumen is respecting their own specifications. These will be sent to me by Mr. Tibor Nemeth and I will pass them to you.

Enclosed you will also find an English version of my paper that was included in the Graz conference file. Translation with us in Belgium is also very expensive (+ 0.50 US$ per line). So it would be a large amount of money to spend. Anyway, I will send you the papers we will present at the Kuala Lumpur Symposium later this year. This Symposium will be in English.

Meanwhile, I charged our Accounting Division to send you a check of 340.- US$ to cover your service expenses of the first half of 1988.

Best regards to you and Sandra,

Sincerely,

Hugo Van de Velde