ABSTRACT. The South African Roads Industry is aware of the success achieved with bitumen rubber over the last 25 years. Due to its visco-elastic behaviour, the binder requires elevated temperatures to handle the product in sprayed seal and asphalt applications. The experience by the roads industry of the rapid deterioration of bitumen rubber when handled at high temperatures during sprayed seal applications created perceptions regarding the use of bitumen rubber in asphalt applications. One of the perceived drawbacks of bitumen rubber in asphalt application is its limited shelf-life. While investigating flushing problems during the construction of the bitumen rubber asphalt semi open (BRASO), it was implicated that these problems may have been as a result of binder degradation associated with the limited shelf-life of the binder at high temperatures. The bitumen rubber suppliers and asphalt manufacturers were requested to conduct shelf-life studies to duplicate the bitumen rubber binder’s time-temperature profiles at various scales of operation. The shelf-life studies included laboratory blends with two different grades of base binder and static and dynamic storage tests. The laboratory study was also repeated on a large scale, manufacturing bitumen rubber through a sprayer unit. The properties of the product were monitored over a twelve hour period and the asphalt properties of the aged binder at different stages of ageing were tested to assess the impact of binder ageing on the BRASO behaviour. These studies revealed important facts that are often misunderstood. In this paper, the misperceptions of bitumen rubber shelf-life are addressed and the effect of the base binder, the scale of operations and the storage stability will be contextualised indicating a much improved actual shelf-life in asphalt cement relative to the current 4-6 hours allowed.

KEYWORDS: Bitumen Rubber Shelf-life, Ageing Rate, Asphalt Rubber

Asphalt Rubber (USA) = Bitumen rubber (Australia, Europe and South Africa)
1. Background

1.1. History of Bitumen Rubber in South Africa

In South Africa, bitumen rubber has been used successfully since the mid 1980’s. The South African Roads Industry is therefore aware of the successes achieved with bitumen rubber over more than 25 years. Bitumen rubber was used extensively in both sprayed seal and asphalt (cement) applications. The properties of the product are covered in Standard Specifications for Road and Bridge Works for State Authorities Committee of Land Transport Officials (COLTO)[1], Sabita Manual 19 [2] and the Guidelines for the use of Modified Binder in Southern African Region Technical Guideline 1 (TG 1) [3].

In these documents the bitumen rubber product described is largely based on the successful application of bitumen rubber produced with the wet method. The final product specification of the modified binder is therefore documented and specified for quality control and quality assurance purposes.

The perceived poor shelf-life of bitumen rubber is a well-known limiting factor [1,3] and many specifying authorities are therefore cautious when it comes to the use of bitumen rubber in tender specifications. However, the superior performance of the bitumen rubber binder is associated with the increased durability of the asphalt and seal applications despite the conservative hesitance to use this product type. It is largely and widely accepted, well documented and known within the South African Roads Industry. Bitumen Rubber is therefore widely used and specified in different asphalt applications such as Bitumen Rubber Asphalt (BRA) and variations on the theme depend on the aggregate gradation i.e. BRAC – continuously graded asphalt) and BRASO - semi-open graded asphalt [2]. In contrast to the accepted practice in the USA where bitumen rubber is primarily used in Open and Gap graded asphalt mixes [4], South Africa also uses bitumen rubber in denser aggregate mixes.

1.2. BRASO Investigation

The planned freeway upgrade in the larger Gauteng area involved the use of bitumen rubber on most of the sections in the Stress Absorbing Membrane Interlayer (SAMI) as well as some 600 000 metric tons of BRASO. Construction on the Gauteng Freeway Improvement Project (GFIP) Phase 1 started in 2009 before the 2010 FIFA Soccer World Cup and continued into 2012. Large sections of continuously reinforced concrete and block concrete sections of the N1 (Western Bypass), N3 (Eastern Bypass) and N12 (Southern Bypass) were overlaid with BRASO.

Sporadically, bleeding and flushing phenomena were observed and despite numerous investigations into the origin of the “bleeding spots”, the statistical significance of trends could not be linked conclusively to specific material properties, plant / production processes and / or construction conditions. Although the extent of the failures constituted less than 4%, certain sections on Package B were aesthetically very unsightly and were considered dangerous from a skid resistance perspective on the highest traffic volume highway in Southern Africa. An investigation into various aspects of the mode of failure on Package C was conducted by independent, internationally acclaimed asphalt rubber specialists during 2011 [6].

Tosas (Pty) Ltd (a binder supplier) and Much Asphalt (Pty) Ltd (an asphalt supplier) on these sections were asked to conduct asphalt and binders studies to assist in the investigation. The data presented in this paper constitutes some of the results which were produced by Tosas and Much Asphalt and used in the investigation report [6]. The data in this paper however only covers the aspects and interpretations vital for the understanding of the sensitivity of the shelf-life of the bitumen rubber product as a generic product type.

2. Reaction Curves – Digestion Curves – Time Temperature Curves

Bitumen rubber is regarded as a very high temperature product and the typical handling temperatures are in excess of 190°C. The product is typically manufactured at 200°C (±5°C). The physical and rheological properties are largely determined by the ratio of components. The standard product in South Africa consists of blend of 80 mass% bitumen (78 mass% bitumen with 2 mass% Extender Oil) and 20 mass % rubber crumbs. The theory of the mechanism dictates that the lighter fractions of the high molecular weight aromatic component in
bitumen are absorbed into the rubber crumbs and this leads to an increase in viscosity of the blend. The rubber particles in this blend swells and the outer edge of the crumbs and finer rubber particles are then degraded to a gel-like substance with the resultant reduction in the viscosity again (Figure 1). If the process is allowed to continue all the rubber particles will be absorbed into the bitumen portion of the blended two-phase or non-homogenous system. The eventual resultant product has rubber crumbs with a different morphology and reduced size [7]. The rubber crumbs play the predominant role in the elasticity of the binder and the degradation of the rubber particles reduces the elastic component of the bitumen rubber binder. The elastic behaviour is less pronounced when the rubber crumbs are fully digested and the product then behaves more like a conventional binder where the viscous component (in rheological terms) predominate.

![Figure 1. Stages of rubber particle degradation](image)

The success of the bitumen rubber systems is however dependent on the fact that the majority of the rubber particles are still intact in the blend. Therefore the rate of reaction (absorption, swelling degradation) will determine the shelf-life.

Factors that influence the rate of reaction are given below:

- Temperature during and after reaction
- Rate of heating
- Type of agitation (Auger or paddle stirrers)
- Pressure and duration bitumen rubber is subjected to circulation
- Composition, shape, surface texture and gradation of rubber crumbs
- Composition of base binder and extender oil

Of the mentioned factors, temperature and time have the biggest influence on the reaction process when all other conditions / components are kept constant.
This time-temperature dependent behaviour is best illustrated when the effect of time and temperature on the physical properties are plotted on a single graph. Typically the changes in viscosity, softening point and flow properties are used to monitor the reaction and the rate of degradation in Figure 2.

Figure 2. Trends of the effect of temperature on physical properties

3. Time Limitations related to the use of Bitumen Rubber product

Since the product has a limited shelf-life, it is therefore necessary to prescribe the time limit for use of the product to ensure quality and performance in the application of bitumen rubber. Although each supplier’s product is described by its own method statement, the tender documents and industry guidelines are very much prescriptive in nature. The Client and their appointed representative (Consulting Engineers) monitors activities and the governance related to the use of the product (both binder and binder aggregate mix) by means of pro-forma specifications that are based on national guidelines.

3.1 Asphalt Manufacturing

Bitumen rubber is produced at 195-200°C and, in most instances, it is transferred via a header tank into the asphalt mixing plant and mixing is typically controlled between 175 and 180°C. The bitumen rubber is supplied to continuous
6 The Perceived vs. Actual Shelf-Life and Performance Properties of Bitumen Rubber

drum mixing plants via a two pump system where the second pump is used to measure the volume of binder that is fed.

3.2 Seal Construction

In seal applications the aim is to produce an elastic binder with the capability to adhere to the embedded road stone. Bitumen rubber is one of the most popular binders used in South Africa for seal applications (chip seals, sprayed seals, surface dressings). Many variations of seal types have been constructed successfully varying from grit seals (graded minus 4,75mm crushed stone, 6,7mm and up to 9mm), 13,2mm single seals, double seals (19 / 9,5mm) as well as Cape seals [5, 8].

The important common denominator between asphalt and seal application is that, depending on the temperature, the shelf-life of bitumen rubber is perceived to be very short.

A maximum shelf-life of 4 and / or 6 hours is therefore dictated depending on the experience of the specifying agent and whether it is a seal or asphalt application. Due to a lack of understanding and a conservative approach to quality assurance, the 4 hour limit applicable for seal applications (where the product is handled at high temperature in a bitumen distributor) is applied in an asphalt application environment. This places unnecessary limitations on the rate of asphalt production.

4. Effects of Reaction Temperature on Bitumen Rubber properties

The time-temperature dependence of bitumen rubber properties are well-known and an example of the behaviour is depicted in Figure 3.

During the investigation into the bleeding problems associated with the BRASO used in the Gauteng Freeway Improvement Project, various 12 hour studies were requested by Dr. Sousa and Mr. Renshaw to support their postulations - relating the behaviour of the BRASO observe on the GFIP Package C section to conditions during manufacturing and construction [6]. In the experimental section, the various time-temperature study approaches which were requested to address concerns related to conditions on site, are described. The objective was to simulate conditions which may have impacted on the binder properties and behaviour from a shelf-life perspective.
5 Experimental Program

5.1 The Effect of Static Storage at High temperature on Bitumen Rubber

A static storage test with a vessel (diameter 15cm and 50cm high) designed by Sousa and Renshaw [6] was used to illustrate that the bitumen binder segregates without agitation and may lead to variation in binder properties.

5.2 The Effect of High temperature on Bitumen Rubber monitored with a Laboratory Blender

A laboratory blender with a 30 litre capacity, fitted with pressure gauges, spray nozzles and a roper pump, used for circulation of the product on the bitumen distributors was used for the evaluating the effect of temperature on the binder properties during 12 hour on laboratory scale. An oil heating system with temperature control maintained the blends at a specific temperature for the duration of tests.
5.3. The Effect of High temperature on Bitumen Rubber Monitored on Plant Production Scale

The *modus operandi* was to manufacture bitumen rubber in a sprayer unit with a ~15 000 litre capacity. The bitumen rubber product was manufactured and reacted for 2 hours. Approximately 9000 litres were then used for asphalt production and the remainder of the batch, approximately 6000 litres was kept for a 12-13 hour period. Samples were taken every hour and the binder and asphalt properties were tested for the duration of the plant trial.

5.4. Binder Testing

The viscosity of bitumen rubber properties produced in the sprayer unit was monitored with RION Viscometer (as per the prescribed method MB-13). The bitumen rubber samples (5 x 1 litres) which were taken at hourly intervals was cooled and returned to the laboratory where it was reheated for 2 hour at 200°C, the following day according to method MB-2 of TG1. Standard procedure for the determination of softening point ASTM D36, flow MB-12, compressions recovery MB-11 and resilience MB-10 were followed [3]. The results are reflected in Figure 5. The flow test is and indirect measure of the viscosity of bitumen and conducted at 60°C. The flow is measured as the distance (in millimetres) a moulded 3.2 x 20 x60mm bitumen rubber at an 35° angle.

5.6. Asphalt testing

The volumetric properties of an asphalt mix are influenced by a number of factors such as gradation, aggregate shape, strength and texture, compaction-effort as well as binder viscosity at the compaction temperature. In the event that the binder viscosity change - and all the other factors stay the same - one would therefore expect the volumetric properties to change as well (Lower viscosity would result in lower void content). The effect of the viscosity change over time of the bitumen rubber binder, on the volumetric properties of BRASO, was assessed in the laboratory by mixing laboratory samples using the bitumen rubber samples that were taken every hour in the bitumen rubber time study described earlier. The bitumen rubber samples were still hot and used directly after the samples were taken and mixed with pre-heated aggregates as per the job mix formula. The asphalt samples were then conditioned in an oven at 180°C for 45 minutes before compacting the Marshall briquettes at 145°C. The volumetric
properties of the briquettes were determined and the results are given in Figure 6 below.

5.7. Evaluating the impact of transport on Asphalt properties

The effect of the ageing of the bitumen rubber binder in the BRASO - after it has been mixed in an asphalt plant - was assessed by taking samples every hour from a parked asphalt delivery truck at the laboratory. The asphalt was transported from the asphalt plant where it was manufactured to another asphalt plant some 40km away where the time study was done. This was to simulate the effect of transporting the asphalt to a construction site. The asphalt samples were compacted at 145°C without oven conditioning. The volumetric properties of the briquettes were determined and the results are given in Figure 7 below.

6. Results

6.1. The Effect of Static Storage at High temperature on Bitumen Rubber

Binder segregation was actually not the case for binder produced during the Gauteng Freeway Improvement Project contracts as strict time delivery schedules were set by the production teams at various Asphalt plants. In Figure 4, it is however noteworthy that the properties after 12 hours vary significantly without agitation and that the top portion of the binder in the vessel almost reverted to bitumen with a low modification of SBR. This supports for the theory of the particle degradation in Figure 2. As expected the degree and extent of the segregation was higher at 200°C than at 175°C.

![Figure 4. Trends of the effect of temperature on viscosity of bitumen rubber](image-url)
6.2. The Effect of High temperature on Bitumen Rubber monitored with a Laboratory Blender

It was found with past experience that the time temperature profiles produced with this laboratory blender closely resembles the actual bitumen rubber behaviour in a bitumen rubber distributor unit and was used to produce the time –temperature graphs required for commercial purposes (Figure 3).

At 190°C the bitumen rubber properties are the closest to the actual time-temperature behaviour. At 200°C the rate of degradation in the laboratory was substantially higher than what is actually achieved in practice. It was therefore difficult to indicate the effect of the change in base binder from 80/100 to 60/70 penetration grade bitumen. This was mainly due to the scale, pressure and rate of the pumping action in the laboratory blender relative to the actual production conditions. This resulted in the investigation team (Dr Sousa and Mr Renshaw) requesting that the exercise be conducted at plant scale to monitor the effect of temperature on large scale.

6.3. The Effect of High temperature on Bitumen Rubber Monitored on Plant Production Scale

The results from this full scale time temperature exercise (Figure 5) were again expected since it corresponds with past experience (Figure 3). It was however also surprisingly insightful to observe the impact of the scale tests and operations on the time – temperature exercises made a significant difference in the behaviour of the bitumen rubber. It was found that the bitumen rubber was still within the allowable physical property limits specified in the TG1 guidelines, even after a 13 hours period at 200°C [9]. When the exercise was repeated at a lower temperature (175°C), again the expected trend was observed.

Bitumen rubber is well known to have vast improved properties at lower temperatures. The only drawback is that bitumen rubber cannot be sprayed at 175°C. Due to the higher viscosity at these suggested lower temperatures, the perception exists that it may be more difficult to mix bitumen rubber with the aggregate but, it was proven by Much Asphalt that asphalt mixing at 175°C is achievable. Renshaw and Sousa therefore concluded that, if the handling
temperature of the asphalt (asphalt cement) is reduced from 200°C to 175°C, the effect of the binder degradation on the asphalt behaviour can be minimised.

Figure 5. Trends of the effect of temperature on bitumen rubber properties

6.4. Aged Bitumen Rubber time study (Laboratory mixed asphalt)

The test results are contrary to what would be expected as there is no clear reduction in Marshall Voids of the longer aged – lower viscosity – bitumen rubber samples. Although a slight downward trend can be noticed in Figure 6 from 1 hour up to 11 hours where the Marshall voids reduced from 7.7% to 6.6% the 12 and 13 hour samples had higher Marshall Voids of 7.4% and 7.1%. This could be a testing anomaly that could relate to the repeatability of the test method.

Figure 6. Effect of Age of Bitumen Rubber on Marshall Voids of BRASO
6.5. Aged BRASO time study (Plant mixed asphalt)

The aggregate gradation of plant mixed BRASO was slightly finer than the job mix formula, which resulted in lower Marshall void content being achieved on all the samples of this time study with Marshall void contents ranging from 3.7% to 4.6%. There was again no clear trend that the Marshall void content decreased as the asphalt got older and the variability in test results can rather be ascribed to repeatability of the test.

Various similar time studies were done on other BRASO mixes in South Africa and none showed a drastic decrease in Marshall Voids over time. This could possibly be ascribed to the low Marshall compaction temperature used in South Africa ranging from 135°C to 145 °C which is much lower than the temperature at which the viscosity test is performed (190°C). It is possible that, at such low Marshall Compaction temperatures, the difference in viscosity would not influence the volumetric properties - as determined in the Marshall method - of the BRASO and a difference would only be seen at higher compaction temperatures.
Figure 7. Effect of Age of BRASO on Marshall Voids (Plant mixed asphalt)

7. Conclusion

In this paper, the authors illustrate that:

1) The scale of product makes a significant difference in the assumptions and postulations related to the behaviour of any material and even more so in the case of bitumen rubber.

2) The effect of temperature is not as severe on the binder in storage (with auger agitation) as in a sprayer unit. The relative degradation for a product circulated through a spraybar system at high pressure with gear pumps is much more severe.

3) The actual time for the product – in asphalt (concrete) applications - to drop below the acceptable limits (as stipulated in TG 1) is much longer than the 4-6 hours allowed by consulting engineers as per current guideline principles.

4) The reduction of temperature as Renshaw and Sousa illustrated will prolong the shelf-life of bitumen rubber asphalt product.

5) The asphalt properties blended in the laboratory has shown very little variance at both 200°C and 175°C.

6) Although Renshaw and Sousa used the degradation of binder and related it to the standard best practice, it must not be confused with other recommendations to reduce the potential of an asphalt mixture to bleed. Bleeding is related to the volumetrical packing of aggregate, binder and air voids are essential to prevent an asphalt from bleeding.

7) Segregation in trucks and a lower binder viscosity at the specified high storage temperatures may have contributed to the problem.

8. Recommendation

The South African Roads Industry is taking cognisance of the effect of time and temperature on the bitumen rubber binder and the bitumen rubber asphalt’s behaviour and the review of the Sabita Manual 19 for the use of bitumen rubber in asphalt.
1. The effect of the Marshall compaction temperature on the volumetric properties of BRASO manufactured with bitumen rubber with different viscosities should be further assessed.

2. In an attempt to promote a higher volume the Rubber Pavements Association and practitioners in the global arena must take cognisance of the effect of warm mix technologies and encourage the use of these technologies to alleviate the problems associated with the use of this high temperature product and realise that a new generation of bitumen (asphalt) rubber is practically possible and will to reduce the effect of temperature on the shelf-life [10].

3. Although bitumen rubber is the most durable binder known to the global roads industry, the challenges associated to the higher operation and mixing temperatures required are problematic in terms of worker safety. Additionally, the perceived reduced shelf-life requires more client and consulting engineering education to ensure the successful application of the bitumen rubber technology.

4. More attention to detail during construction will ensure better performance. In essence, attention to the detail such as handling and compaction temperatures during construction will improve the performance of bitumen (asphalt) rubber in sprayed seal and asphalt (cement) applications and in combination with warm mix technology pave the way to a higher volume of bitumen (asphalt) rubber being specified.

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9. Bibliography


