New Bitumen Rubber Technology Improves Storage, Handling and Stability of Bitumen Rubber

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ABSTRACT. *Bitumen rubber is globally known to be the best modified binder from a rheological and a durability perspective. Due to its visco-elastic properties, the product must be handled at very high temperatures (relative to other binders used in similar applications) and it has a limited shelf-life at these elevated temperatures. Despite the excellent performance of the bitumen rubber product, it is often disregarded as a result of the complexity of the operation and the risk associated with the product. These concerns can be addressed by lowering the handling and application temperatures. The integration of a warm mix wax additive in bitumen rubber manufacturing, allows for lower handling and application temperatures. This is aligned with the global focus on the reduction of temperatures during asphalt manufacturing and paving, to improve worker health and safety, while reducing the carbon footprint. A "stabilized warm mix rubber asphalt binder" that can be produced at reduced temperatures with an increased stability over time is now possible with the use of innovative compounds of ground tyre rubber, swelling agents and warm mix wax additives. The combination of a Fischer-Tropsch wax additive and a swelling agent decreases the viscosity of the reacted binder significantly and improves the handling and compaction behaviour of the asphalt mixes. It further allows lowering the production and paving temperatures from ~200°C to ~160°C. This rubber compound technology overcomes current drawbacks of rubber modified asphalt enabling the use of this technological to deliver environmentally beneficial pavements.*

KEYWORDS: *Bitumen Rubber Shelf-life, Warm Mix Technology, Asphalt Rubber `*
Asphalt Rubber (USA) = Bitumen rubber (Australia, Europe and South Africa)

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1. Background

The first bitumen rubber was developed in Arizona when Charles McDonald used rubber crumbs from scrapped vehicle tyres to produce a joint or crack sealant for concrete roads [1]. The properties of this product were manipulated and progressively bitumen rubber found its way into the chip seal and later asphalt applications. South Africa imported the bitumen rubber technology in the mid 1980’s and refined the properties, applications and specifications to suite the local conditions [2]. After more than 25 years of success with bitumen rubber used in asphalt and seal application, the product still remains a mystery to most clients and specifying authorities.

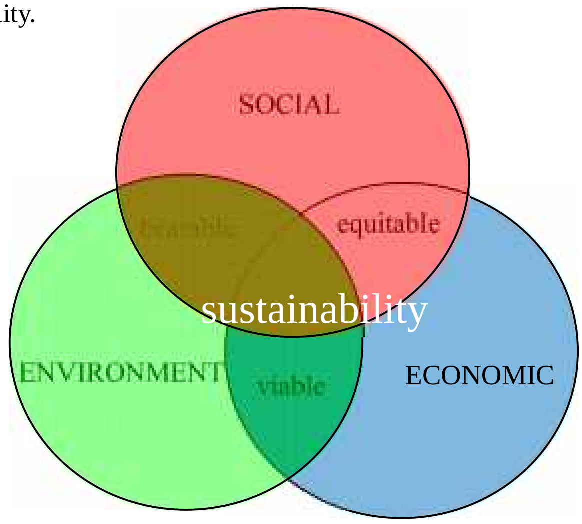
Globally, the biggest challenge with bitumen rubber is the extremely high temperatures at which this product is manufactured and used. Due to its very high viscosity, it is necessary to handle the product at temperatures above 190°C, (approximately 200°C during manufacturing). The shelf-life at this high temperature is limited and this restricts and complicates the successful use and application of the superb product. Despite the challenges, manufacturers, asphalts producers and authorities devised procedures to ensure a good quality paving as end-product [3].

2. Advent of Warm Mix Technologies

In the mid 1990’s the use of Fischer-Tropsch hard waxes was proven to introduce higher softening points at ambient and at high road temperatures but allowed the reduction of viscosity of the mixture above the melting point of these waxes [4, 5]. The use of this concept has since evolved into a well established product range which is successfully used to produce rut resistant asphalt mixes. In the mid 2000’s the global roads industry realised that there are more advantages related to the use of this additive and started to harness the benefits of reduced mixing and compaction temperatures[6]. In South Africa extensive work and trials were performed to investigate the use of the additives, chemical and foam technologies. Following the Warm Mix trials, a guideline and testing protocol was developed [7]. It was therefore only a matter of time before the roads industry started to work with the idea of incorporating the benefits of the warm mix technology using modified binders. Bitumen rubber was no exception and the addition of the additives that reduce viscosity was investigated. The changes in the physical properties indicated a potential benefit [8] but still required the initial high temperatures to produce bitumen rubber. The sequence and addition level of the various components were still under development and this process was challenging [9].

3. Requirements for New Bitumen Rubber Technology Development

Since 2010 there has globally been an increased focus with regards to the impact of operations on the environment, worker safety, energy usage and the overall carbon footprint. Terms like the triple bottom line approach to business accounting became important and not just the economical benefits. The environmental and social impacts now also need to be taken into account; the focus is now on sustainability.



The global drive to move to greener (more environmentally friendly) products is now taking precedence [10]. However, technologies also have to provide good quality final products. Bitumen rubber has been promoted by the Rubber Pavement Association as the best way to deal with the ever increasing piles of scrapped vehicle tyres. Thus, by taking the energy balance and the impact on the carbon footprint into account, it is not difficult to show that the use of the rubber in modifying road surfaces is a better application than for instance burning the rubber or dissolving it as a homogenous component in terminal blend technologies [11].

High temperatures associated with the use of bitumen rubber makes it less desirable when worker safety and exposure limits are considered. The European (German) exposure limit for temperature is set at a maximum of 180°C. The allowable limit of volatile organic components is also restricted by similar legislation [12]. Legislation regarding worker safety and exposure limits in Europe and Germany is unfortunately quite complex and to some extent unclear. Based on changes in the German Hazardous Materials Act, the former limit for exposure to fumes and aerosols from bitumen of 10 mg/m³ is no longer applicable and the temperature limit for Gussasphalt (mastic asphalt) is 230°C since 2008. Under REACH (European chemicals legislation), a derived no effect level (DNEL) of 2.6 mg/m³ fumes and aerosols from bitumen (for workers) was calculated from animal studies. However, as bitumen is not classified as dangerous, this limit is not a legal exposure limit, but more a guideline. To complicate matters further, this limit is mostly exceeded, even in the instance where warm mix technologies are applied. Specifically for bitumen rubber, a working group of the FGSV (German Transportation Research Society) is currently finalizing the document “Guidelines for modifying asphalt with rubber”. The draft of this document limits the binder production temperature to 180°C and the paving temperature for the mix to 170°C.

Despite the fact that bitumen rubber increase the durability of asphalt and seal applications, as proven in the United States and South Africa over more than 25 years and more recently in Europe, China, etc., bitumen rubber still remains the least understood of the modern modified binders amongst the Client Bodies, Engineers, Politicians and Manufacturers.

The use of Bitumen Rubber is complicated by its limited shelf-life at high temperatures and paving crews and sprayer operators dislike the odours (Old Sneakers’ Smell) associated to the product. The use of an extender oil adds to the suspicion, mystery and misery and, despite changes in base bitumen properties over the last 30 years globally, a vast degree of ignorance and lack of ability to appreciate the huge advantages associated with the use of this product type still exist.

In order to make the bitumen rubber product more user friendly, the following criteria have been identified:

- Reduce the temperature required to manufacture and apply the product from ~200°C to below 180°C
- Reduce the viscosity of the product to accommodate the reduction in temperature
- Maintain or improve toughness levels of the product
- Maintain or improve elastic response of the product
- Improve/increase the shelf-life of the product
- Reduce the sensitivity to time and the ever-changing physical properties of the product
- Reduce the asphalt mixing or spray application temperatures
- Reduce the sensitivity to temperature and the requirement of compaction at high temperatures.

Work in progress has demonstrated that all of the objectives set by the research team are achievable. A diverse team (background and application experience) worked towards the achievement of the ultimate goal; the development of a

Bitumen Rubber Technology enabling lower temperature requirements with reduced viscosity, improved storage stability and safer handling - A “stabilized warm mix rubber asphalt binder” (StWaMARAB)[13]. A variety of different stabilising and warm mix additives were evaluated in combination with rubber crumbs but only data pertaining to the manufacturing and properties of bitumen (asphalt) rubber was used in this paper.

4. Experimental

4.1. Blending equipment

Bitumen rubber samples were prepared with a laboratory scale, bitumen rubber blender with a 30 litres capacity fitted with pressure gauges, spray nozzles and a roper pump used for circulation of the product on the bitumen distributors. An oil heating and temperature control system allows blends to be maintained at a specific temperature for the duration of a test. It was found, with past experience, that this unit closely simulates actual bitumen rubber behaviour in a bitumen rubber distributor unit. This unit was used to produce the time – temperature graphs required for commercial purposes [13].

4.2. Sample preparation and blending conditions

Conventional bitumen rubber mixture, with a ratio of components Bitumen: Extender Oil: Rubber Crumb of 78:2:20 on a mass % basis, was compared with a rubber technology referred to as pre-treated rubber in Table 1.

Sample code	**Compound (m/m%)	Sample Description
A	20	Conventional Bitumen Rubber at 190°C
B	20	Conventional Bitumen Rubber at 180°C
C	20	StRAB without Warm Mix Additive at 180°C
*D	20	StWaMARAB with Warm Mix Additive at 180°C
*E	20	StWaMARAB with Warm Mix Additive at 180°C
*F	22	StWaMARAB with Warm Mix Additive at 180°C
*G	24	StWaMARAB with Warm Mix Additive at 180°C

* Sample D was selected from a number of various formulations [8], the compound was then manufactured on large scale and samples E, F G consisted of the large-scale manufactured compound at the respective dosage rates of 20, 22, 24%

** The term Compound describes rubber crumb with additives

Table 1. *Composition of conventional bitumen rubber and new bitumen rubber technology blends*

Conventional bitumen rubber blends were prepared at two temperatures. At 190°C, the behaviour is comparable with commercial bitumen rubber blends and at 180°C the behaviour is comparable with the new bitumen rubber technology.

Bitumen (80/100) was preheated to 200°C, the extender oil was added, followed by the addition of the rubber crumbs. The temperature of the respective blends was dropped to 180 and 190°C and was maintained at the two temperatures for the duration of 6 hours.

By combining bitumen and the pre-treated rubber in the bitumen rubber blender at 180°C for the duration of six hours it was possible to determine the effect of the changes on the physical properties such as viscosity, softening point and flow properties over this time. The pre-treatment of rubber crumbs involved exposure to a variety of swelling agents, stabilising agents and warm mix additive (WMA). The New Bitumen Rubber Technology described in this paper was the result of a selection process based on the advantages demonstrated for a balance of critical physical properties relative to conventional bitumen rubber.

4.3. Physical properties

Viscosity was determined with a hand held Rion Viscometer (similar to Haake viscometer) [14]. Softening point was determined with the ASTM D36 method using a Normalab - automatic Ring and Ball apparatus. Flow measurements were done according to method MB12 [15]. Softening point and viscosity measurements were performed at hourly intervals and the flow test samples were taken at hourly interval but were only trimmed and conditioned after completion of the 6 hour digestion / blending period. The compression recovery (method MB-11)[16] and the Resilience (Ball Penetration) [17] were measured at two conditioning temperatures (25°C and 60°C) to demonstrate the affect of the new technology on elastic response. Although these tests are empirical in nature, the significance and importance cannot be underestimated. Both tests are valuable measurements of the elastic response of the rubber modified binder.

It is important to note that time 0 represents the case when all the components have been combined. In all cases this period equalled 15minutes. Once the trends were determined for the compounds on laboratory scale,

Sample D was produced through a plant manufacturing process on large scale (15tons). Samples D, E, F and G therefore consist of the same compound formulation. Samples E, E and G were only reacted for 1,5 hours in the laboratory blender to confirm the trend observed for the sample D. The effect of the addition level on the physical properties was simultaneously measured comparing Samples D and E at 20% with Sample F at 22% and Sample G at 24%.

5. Results and Observations

5.1. Time-Temperature Viscosity Relationship

In Figure 1, the typical behaviour of conventional bitumen rubber is demonstrated with the shift in the peak and rate of deterioration in the viscosity when the temperature is dropped from 190°C (Series A) to 180°C (series B). Pre-swelling the rubber crumbs with only a pre-swelling additive reduced the viscosity significantly (Series C) and with addition of the warm mix additive the viscosity at 180°C reduced in a similar manner at a 20% addition level (Series D and E). At higher addition levels (22% and 24%) of the compound the viscosity increases significantly again (compare Series F / G in relation with Series D/E).

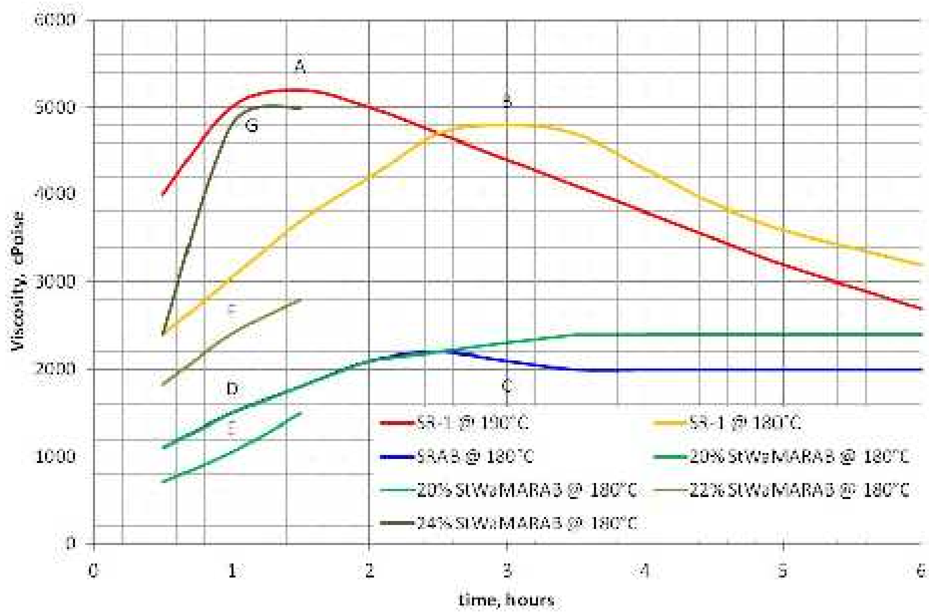


Figure 1. *Time-temperature relationship for viscosity of samples representative of new vs. existing bitumen rubber technology*

5.2. Time-Temperature Softening Point Relationship

In Figure 2, the impact of the new bitumen rubber technology on the softening point demonstrates similar time related trends as observed for viscosity, with the exception that the beneficial effect of the warm mix additive is clearly distinguishable between Series C and Series D/E/F/G.

The behaviour of the new technology bitumen rubber series indicates that the physical properties are maintained as time progressed after the reaction phase, contrasting to the behaviour of the conventional bitumen rubber series which clearly illustrates the limited shelf-life of the conventional bitumen rubber product at elevated temperatures.

Although the pre-swelling additive (Series C) resulted in a typical, well-reacted bitumen rubber blend, the WMA was essential to provide a more rut resistant binder which is likelier to perform better in areas with higher traffic conditions and high road temperatures.

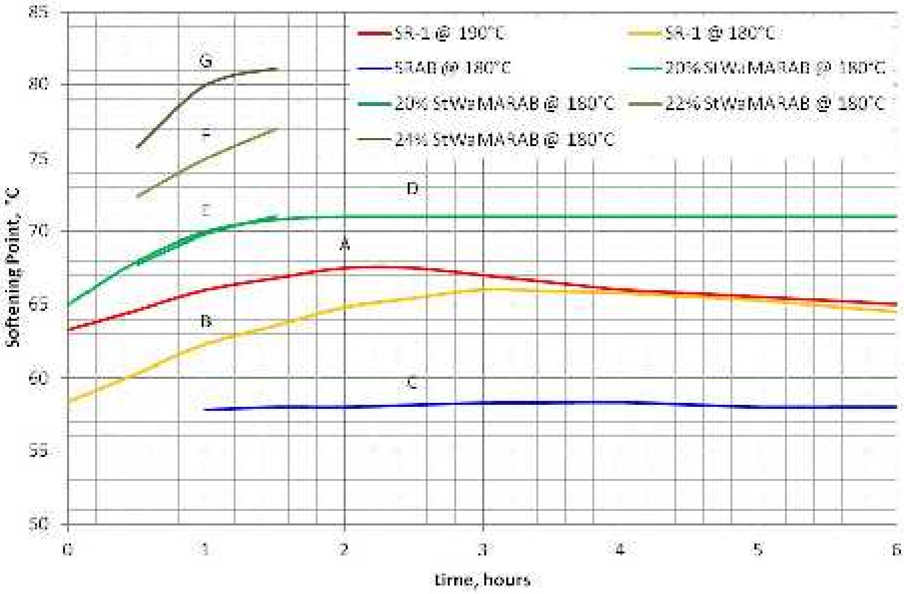


Figure 2. *Time-temperature relationship for softening point of new vs. existing bitumen rubber technology*

5.3. Time-Temperature Flow Relationship

When the flow properties of the binders are compared in Figure 3, a reduction in flow with a reduction in temperature is observed with Series A being the typical behaviour of bitumen rubber at 190°C and Series B at 180°C. The flow behaviour of Series C, as with viscosity and softening point properties, provides a profile of a well-digested bitumen rubber.

The advantages of the WMA in the compound distinguishes the Series D/E/F/G form the typical bitumen rubber behaviour.

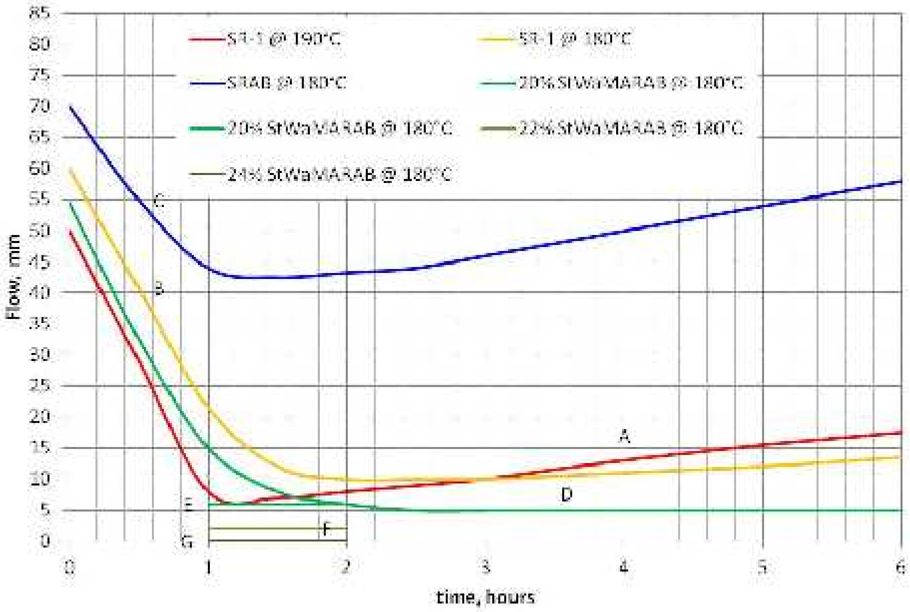


Figure 3. *Time-temperature relationship for flow properties of new vs. existing bitumen rubber technology*

5.4. Comparison of properties of bitumen rubber and the New Technology Bitumen Rubber

The data generated during the comparative evaluation are presented in Table 1.

Properties / Sample code	A	D/E	F	G	Test Method
Viscosity, cPoise @ 190°C	5000				MB-13
Viscosity, cPoise @ 180°C	5000	2500	3000	5000	MC 13
Softening Point, °C	65	74	80	82	MB-17
Flow Test, mm	9	6	2	0	MB-12
Compression Recovery 5 Minutes	92	92	92	91	MB-11
1 Hour	93	95	94	94	
4 Hours	91	93	94	93	
24 Hours	84	89	93	93	
4 Days	65	78	89	85	
Resilience (25°C), %	42	34	32	40	MB-10
Resilience (60°C), %	40	33	34	41	MB-10

Table 1. *Comparison of the physical properties of convention bitumen rubber and new bitumen rubber technology*

6. Conclusion

The new bitumen rubber technology was successful in achieving the objectives set out in the experimental design. The bitumen rubber product's production temperature was reduced from ~200°C to 180°C and, since the viscosity is well below that of convention bitumen rubber at 180˚C, the handling temperature can potentially be reduced to below 175°C. Reduction of the viscosity was achieved by means of including a warm mix additive to the bitumen rubber manufacture during manufacture. The warm mix additive increased the softening point and reduced the flow properties of the modified binder and will provide better rut resistance at higher road temperatures and traffic conditions. The elastic response was maintained and improved by incorporation of warm mix additives. The shelf-life of the new rubber technology improved and the new product now reaches a steady state after 2,5 to 3 hours. In essence, the continuous change with time and the ever-changing physical properties are also removed by using the new bitumen rubber technology. The overall objective to reduce the asphalt mixing or spray application temperatures was achieved.

7. Recommendation

It is expected that the large scale trial tests planned for March / April 2012 will confirm the product behaviour and the trends observed at a laboratory scale. Bitumen rubber remains a difficult product to classify within the Performance Graded bitumen specification and therefore additional work should be done to improve the ability to classify user-friendly New Generation Bitumen Rubber within the Performance Graded bitumen specification in support of the product in the market place. The use of a Dynamic Shear Rheometer will provide an improved understanding of the advantages observed with new bitumen rubber technology.

It is necessary to do carbon footprint and life cycle analysis on the New Generation Bitumen Rubber, comparing it with conventional bitumen rubber and other modified bituminous binders. It is suspected that it will sketch an improved situation when all the factors related to the impact on carbon footprint, reduction in energy consumption and reduced emissions are accounted for. The fact that recycling of used tyres was used successfully for more than 30 years globally in a limited capacity can now be extended with the New Generation Bitumen Rubber technology with improved properties, improved storage stability and improved shelf-life.

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