# Development of a low temperature crumb rubber binder for spray sealing

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## Abstract

Bitumen modified with crumb rubber recovered from used vehicle tyres has been used very successfully in spray applications for many years in Australia. The presence of the rubber improves the properties of the binder and the natural rubber component increases the binder's ability to hold aggregate in place. However one of the major draw backs of using crumb rubber binder in spray sealing applications is the degradation of the binder properties at high application temperatures.

In this paper bitumen modified with crumb rubber and special additives have been studied to improve the storage stability of the rheological properties of the modified binder. The paper also sets out to demonstrate that with special additives crumb rubber can be used in a more environmental friendly and safer manner as a modifier by enabling the binder to be blended and sprayed at a lower temperature without compromising the performance of the seal.

## Background

The utilization of scrap tire rubber in asphalt started in the mid-1960s when crumb rubber was placed in asphalt surface treatments, such as chip seal application. Later on, in the 1970's, crumb rubber modified asphalt chip seals were used as a stress absorbing membranes interlayer. It use has been extended to hot mix asphalt and has continued to evolve due to the rubber's enhancement of mixture performance including improved rutting resistance, thermal reflective cracks resistance, and resistance to fatigue cracking. Some other benefits reported include reduction in maintenance, smooth ride, good risk resistance, and noise reduction (1,2,3,4).

Crumb rubber modified binders can perform equivalently to polymer modified binders and can be used as a substitute for using polymers in asphalt and spray seal binders.

In terms of environmental issues, the disposal of scrap tires is a major waste management concern due to used tires being placed in scrap tire piles and landfills. These stock piles of used tyres become a health risk because they become breeding grounds for mosquitoes and fire hazards.

The rubber composition of tyres contains both natural and synthetic rubber compounds which can be reactivated to react with the bitumen. Crumb rubber from used vehicle tyres is a natural resource of polymers for the local road surfacing industry which negates the need to import expensive polymers into Australia thereby helping the balance of payments and reducing our carbon footprint. The carbon black in the tyre compound is an antioxidant. This helps improve the durability of the binder in the spray seal from the sun's ultra rays and oxidisation.

It has been established that interaction between crumb rubber and bitumen is a physical "reaction" on in which the crumb rubber absorb a portion of the aromatic fraction of the bitumen through diffusion, resulting in swelling of the crumb rubber particles. This particle swelling compounded with the reduction in the oily fraction of the bitumen results in an increase in the crumb rubber binder viscosity. The interaction becomes chemical when the crumb rubber is chemically modified and is used as additive for polymer modified binder. The addition of 10 wt% crumb rubber to C170 base bitumen yielded similar rheological characteristics to those shown by the same bitumen modified with 3 wt% SBS, a polymer widely used to manufacture polymer modified bitumen.

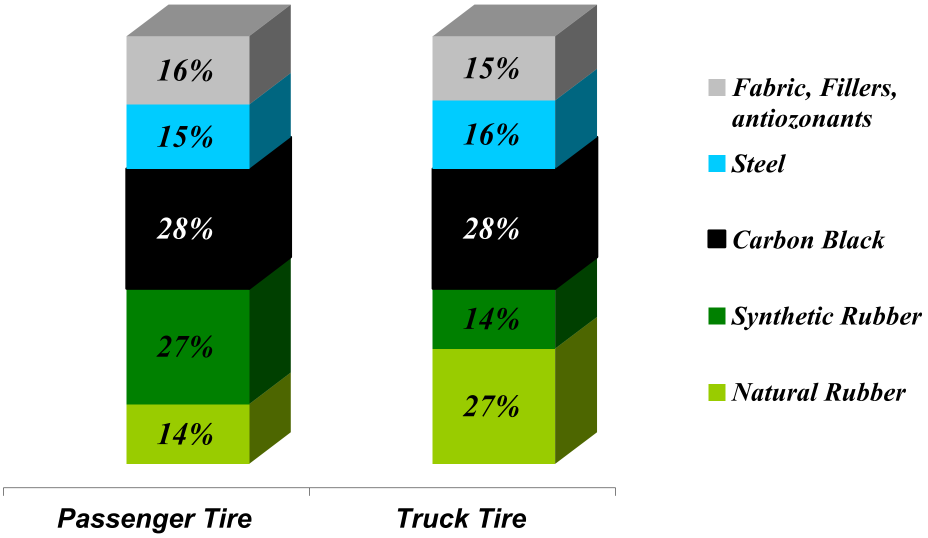

**Figure 1** *Composition of vehicle tyres*

Due to its visco-elastic properties, the product must be handled at very high temperatures. As a consequence this results in the binder having and a limited shelf-life at these elevated temperatures. The crumb rubber binder should be cut back with a lighter petroleum distillate like kerosene just before the binder is sprayed to the pavement surface to reduce its viscosity. The application of crumb rubber bitumen in spray sealing is complicated by its limited shelf-life at high temperature and paving crews and sprayer operators dislike the odours associated to the product.

These concerns can largely be addressed by lowering the handling and application temperatures. To this end laboratory trials were undertaken to see if the temperature at which crumb rubber bitumen could be blended could be reduced to achieve a more storage stable product. The secondary consideration would be to also negate the need to add petroleum cutters and thereby reduce the fuming which is associated with spraying crumb rubber bitumen at high temperatures of 200ºC.

**Figure 2** *Field blending of conventional crumb rubber bitumen*

## Experimental Design

Conventional bitumen rubber blends containing 15% crumb rubber by mass of bitumen were prepared at three temperatures, 190, 200 and 210°C using a mixer IKA 20R from IKA (Germany). Low temperature crumb rubber bitumen blends were prepared from base bitumen C170 and 15% rubber with a low temperature additives. The base bitumen was preheated to 190ºC, the additives were added, followed by the addition of the rubber crumbs. The temperature of the respective blends was dropped to 170ºC and was maintained at this temperature in an oven. The torsional recovery of all the blends was monitored over time against the specification range. Time zero represents the case when all the components have been combined and mixed for 30 minutes at digestion temperature. All the bitumen rubber blends were placed in an oven heated and maintained at their reaction temperature. The softening point has been determined with the Matest - automatic Ring and Ball apparatus according AG:PT/T131. The torsional recovery was measured according AG:PT/T122 using torsional recovery apparatus that operates by manually rotating. The softening point and torsional recovery measurements were performed at hourly intervals until the results were out of the specifications limits of AGPT/T190 – Specifications framework for crumb rubber binder. The viscosity was determined with a hand held Rion Viscometer (similar to Haake viscometer).

Figure 1 illustrates the experimental design followed this study. The crumb rubber binder properties requires by Austroads specification AG:PT/T190 are softening point and torsional recovery (Table 1).

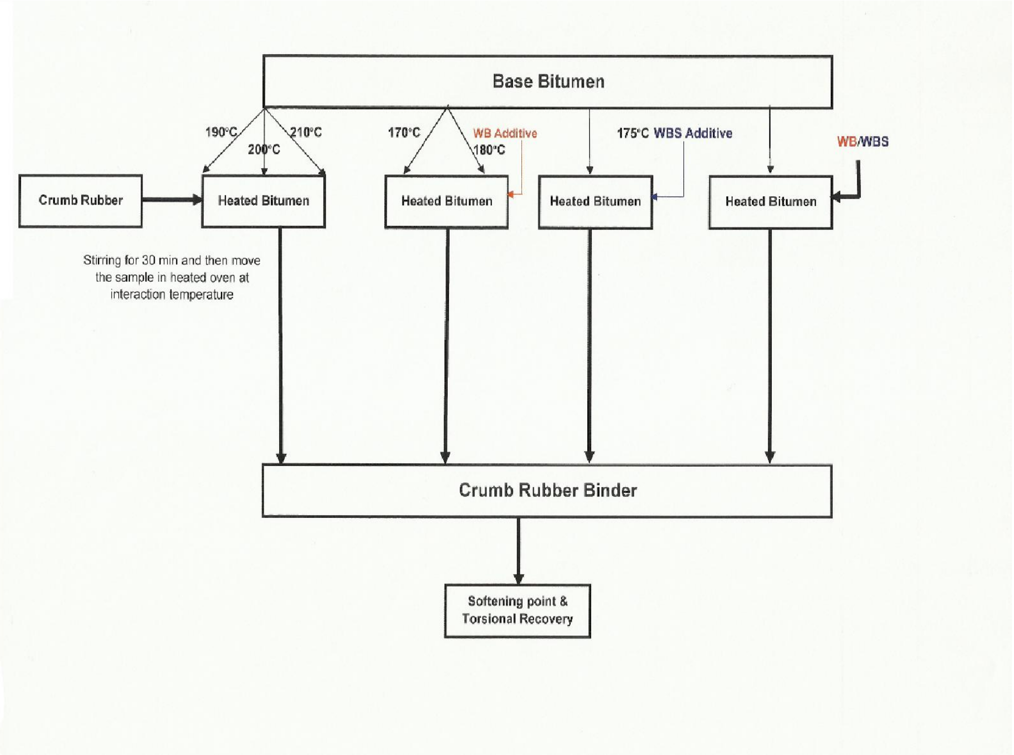

**Figure 2** *Flow chart of experimental design procedures for evaluating the new crumb rubber technology for spray seal application*

**Table 1** *Reological binder property requirements for field blended Crumb Rubber Bitumen*

| **Property** | **S15RF** | **S18RF** | **Method** |
|---|---|---|---|
| Normal Rubber Concentration, [%] | 15 | 18 | |
| Rubber Content by analysis, [%] | 13 | 16 | AGPT/T142 |
| Softening Point, [ºC] min. | 55 | 62 | AGPT/T131 |
| Torsional Recovery, [%] min | 25 | 30 | AGPT/T122 |

The additives used to produce the low temperature crumb rubber bitumen technology are special waxes named WB and WBS.

## Results and Discussions

The crumb rubber binder is formulated and reacted at elevated temperatures and under high agitation to promote the physical interaction of the base bitumen and the crumb rubber constituents. The crumb rubber binder used for spray application requires high crumb rubber contents and should be obtained by the wet blending process. The “wet process” as developed by Mc Donald in the late 1960s the ground tyre rubber interacted with base bitumen at elevated temperature.

In Figure 3, the typical behaviour of conventional crumb rubber binder when stored over time at three different elevated temperatures. This set of data shows a shift in the peak and rate of deterioration in the torsional recovery properties when the temperature is dropped from 210ºC to 190ºC.

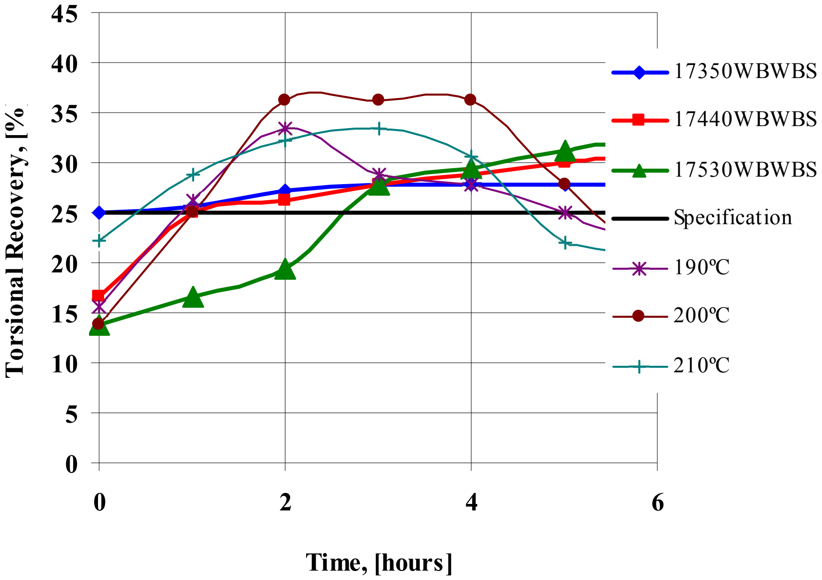

**Figure 3** *Time-temperature relationship for Torsional Recovery of samples representative of new and conventional Crumb Rubber Bitumen for Spray Seal*

The optimum shelf life and peak torsional recovery property is obtained at a temperature of 200ºC for this blend. It should be noted that the torsional recovery property falls below the minimum specification limit of 25% after 5 hours at 200ºC. The three low temperature blends show a slower rate of increase in the torsional recovery property over time. The time required to achieve the minimum torsional recovery value varied depending on the ratio of the additives used in the blend. All low temperature blends maintained torsional recovery values above the minimum limit for the 6 hours during heated storage.

Figure 4 shows the correlation of the viscosity at 190ºC against torsional recovery of conventional crumb rubber bitumen.

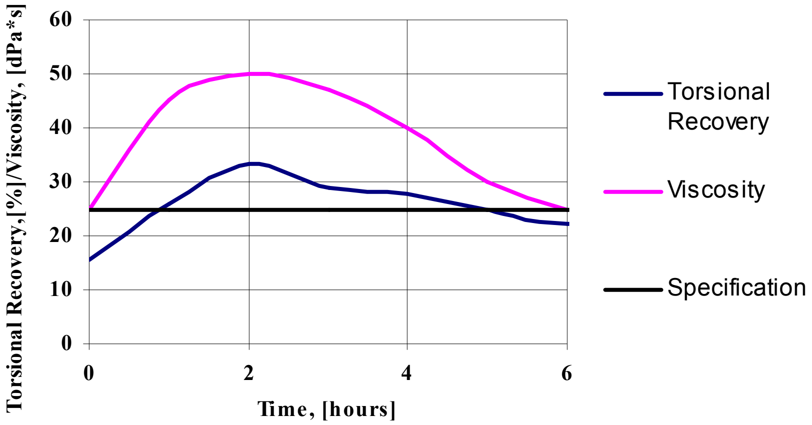

**Figure 4** *Viscosity-Torsional recovery relationship of conventional crumb rubber bitumen*

Figures 5 and 6 illustrate a typical viscosity progression over time and the changes that occur in a typical rubber particle as the interaction process progresses.

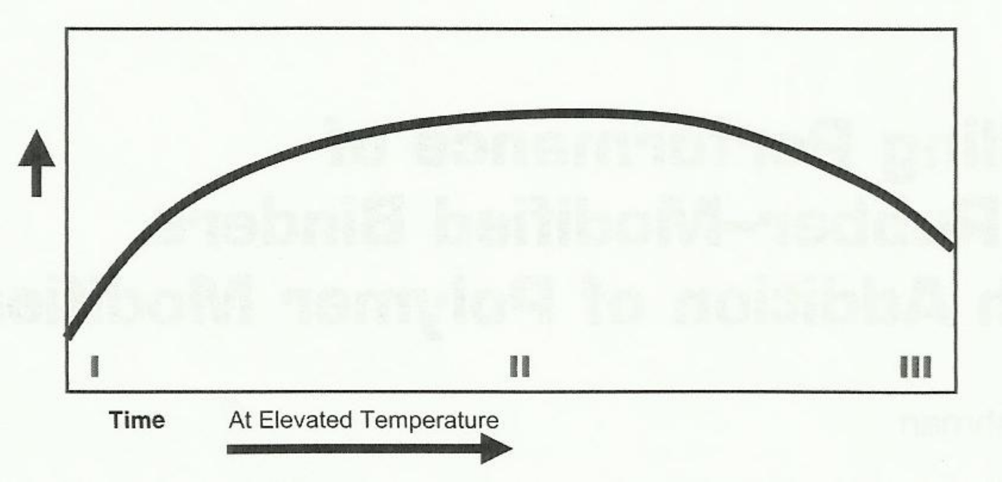

**Figure 5** *Progression of asphalt-rubber interaction at elevated temperature: change in binder viscosity over time at elevated temperature;*

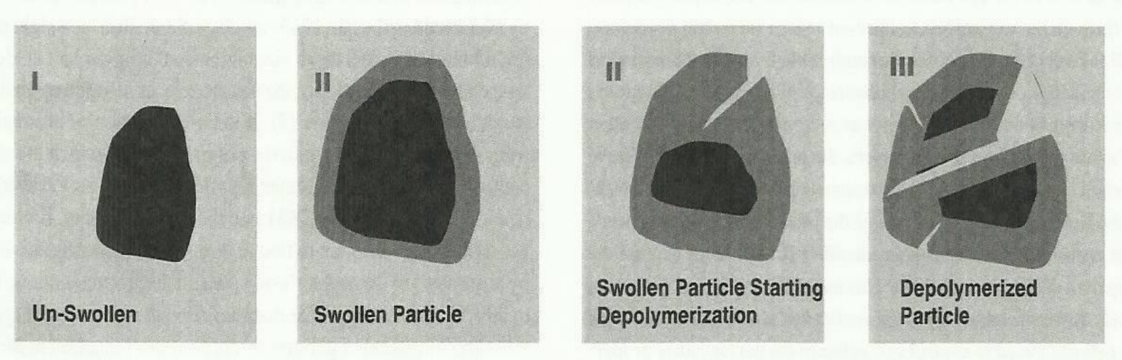

**Figure 6** *Progression of asphalt-rubber interaction at elevated temperature: change in particle size over time at elevated temperature(9).*

It's reported that the rubber particles are swollen to two to three times their original volume by absorption of the bitumen's oily phase at high temperatures to form a gel-like material (5). The change in rubber particle sizes and formation of the gel structures results in a reduction in the interparticle distance between rubber particles and the presence of a modified material, which may produce a viscosity increase by up to a factor of 10 (5,6). Rubber swells in a time and after rubber reaches maximum swelling in the bitumen, if the temperature is too high or the time is too long, dispersion into the binder begins as the rubber experiences depolymerisation because of long exposure to the high temperatures – an undesirable occurrence.

Green and Tolonen emphasize the importance of controlling the swelling processes through controlling the interaction time and temperature and concluded that temperature has two effects on the interaction process (7). The first effect is on the rate of swelling of rubber particles. As the temperature increases, the rate of swelling increases. The second effect is on the extent of the swelling. As the interaction temperature increases at 210ºC for conventional crumb rubber bitumen (see fig.2), the extent of swelling decreases. Particle size controls the swelling mechanism over time and affects the binder matrix.

Buckley and Berger show that the time required for swelling increases with the particle radius squared (8). Abdelrahman and Carpenter concluded that fine rubber swells faster and depolymerizes faster, affecting the liquid phase more than the matrix of the binder, and that coarse rubber has more effect on binder matrix but has less effect on the liquid phase than does the fine rubber (9). Liquid-phase modifications are more stable than matrix modifications. The partial dispersion of crumb rubber in bitumen releases components to the liquid phase of the binder and affects the binder properties. It is explained in the literature as either depolymerisation or devulcanization (10). Both are chemical reactions that reduce the molecular weight of the rubber by breaking chemical bonds. Devulcanization breaks sulphur-sulfur or carbon-sulfur bonds that are formed by the vulcanization process during tire production. The literature on the bitumen – rubber interaction process does not clearly distinguish between the two concepts, particularly at temperature below 240°C (10,11).

The gradual change in the viscosity of the binder has been used to indicate the progress of the interaction between bitumen and rubber. This is the easiest way to check the quality of crumb rubber binder for spray seal application. The viscosity has been measured using a Rion viscotester (see fig 7). The spindle should be inserted in the hot crumb rubber binders sample near the edge of the sample container for about 10 seconds to acclimatise, without plugging the vent holes of the spindle. The spindle should then be lifted out of the crumb rubber binder and moved to the centre of the sample to make the viscosity measurement. The spindle should then be immersed in the crumb rubber binder to the depth mark on the connecting shaft.

Bahia and Davies claim that the increase in binder viscosity cannot be accounted for only by the existence of rubber swelling particles (4). They examined theories commonly used for particulate-filled composite materials to calculate the increase in viscosity of crumb rubber binders and concluded that these theories underestimate the increase in binder viscosity by a large margin. There has to be some type of interaction phenomenon that not only increases the effective volume of the rubber particles, but also changes the nature of the liquid phase. Changes in the properties of the liquid phase of the binder are related to the degree of cross-linking in the material, which in turn gives the material its elastic characteristic, as can be measured by the values of the elastic component (10).

**Figure 7** *Rion Viscotester*.

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Our additives break the asphalten agglomerates and create the possibility for better distribution of asphalten in the malten phase as it has been illustrated in Fig.8. As the additive mixtures break asphaltenes and turn them to individual particles, it is more effective in contributing to extend the shelf life of crumb rubber bitumen.

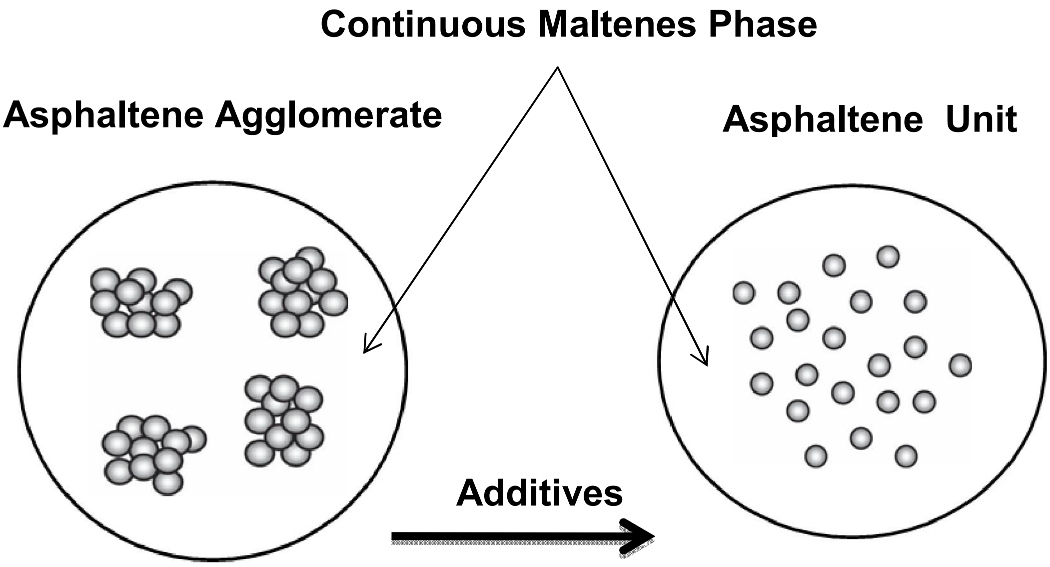

**Figure 7** *The function of additives in bitumen*

In Figure 8, is shown the behaviour of conventional and low temperature crumb bitumen rubber blends with the shift in the peak and rate of deterioration in the viscosity. The viscosity measurements displayed by the three low temperature crumb rubber bitumen blends and the conventional one show the same trends at the respective storage temperature over time as measured using the torsional recovery test.

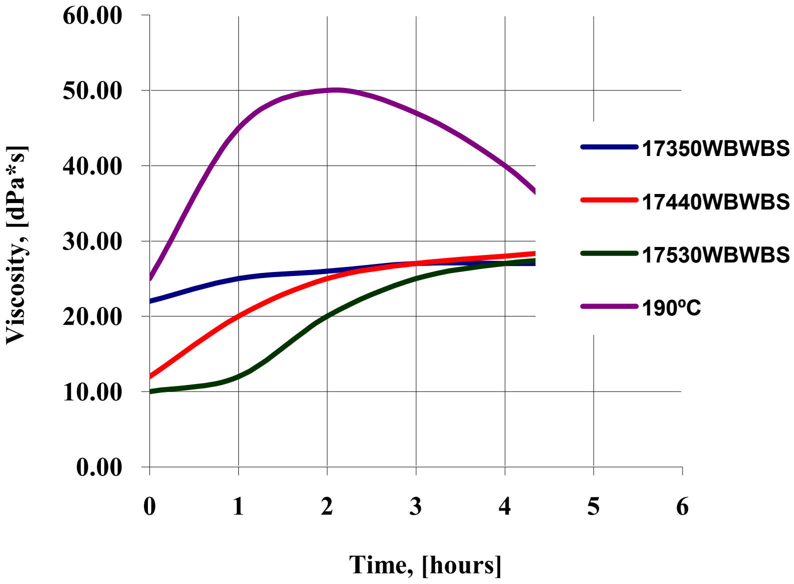

**Figure 8** *Time-temperature relationship for viscosity of samples representative of new vs existing bitumen rubber technology*

## Conclusions

From the experimental results obtained, it may be concluded that the physical properties of bitumen rubber as measured by both torsional recovery and viscosity tests can be extended by using additives and storing at lower temperatures. The study presented demonstrates that interaction temperature can be reduced from 200º to 170ºC to achieve the minimum torsional recovery and softening point requirements for S15RF. The viscosity of the crumb rubber bitumen is an important functional characteristic that can be measured by Rion viscotester. The use of Rion viscotester is a useful tool to evaluate the crumb rubber bitumen in the field as it mimics the torsional recovery properties and can be used to obtain an real time results to ascertain if the product is within specification before application..

The used of crumb rubber from tyres has been in use for more than 30 years globally in a limited capacity and can now be extended through the addition of special additives which will result in improved storage stability at low temperature.

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