

Elastomeric Asphalt Extender – A New Frontier on Asphalt Rubber Mixes

by

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***ABSTRACT:** The Reacted and Activated Rubber (RAR), as an **Asphalt Rubber Binder**, is composed of plain soft bitumen, fine crumb rubber, and an Activated Mineral Binder Stabilizer (AMBS) at optimized proportions. RAR is produced by a short-time hot blending and activation in a specially designed process to form a dried granulated activated rubber. RAR can be added to any type of Hot Mix Asphalt (HMA) – Dense, Open Graded, Gap-graded, SMA, etc., for replacing part of the asphalt cement (bitumen) at different proportions. In the mixing plant it is added directly to the pug mill or dryer drum, right after the bitumen spraying, using existing feeders (i.e. fiber feeders for SMA mixes, etc.). This paper summarizes an R&D Research effort showing that Asphalt Rubber HMA, produced with RAR, outperforms conventional HMA and even regular modified and asphalt rubber mixes. In general, it was found that RAR is an **elastomeric asphalt extender** that modifies the plain bitumen by increasing its PG grading, resilience, softening point and recovery properties. As shown in the paper, Different types of HMA mixes produced with RAR showed much better Stability, Rutting and Fatigue resistance under attractive cost/benefit conditions.*

***KEYWORDS:** Asphalt Rubber, Crumb Rubber, Reacted and Activated Rubber (RAR), Activated Mineral Binder Stabilizer (AMBS), Asphalt Rubber Binder, Hot Mix Asphalt, Asphalt Rubber Mixes.*

1. Introduction

The primary reason for using Asphalt Rubber (AR) in Hot Mix Asphalts (HMA) is that it provides significantly improved engineering properties over conventional paving grade asphalt (bitumen). Asphalt rubber binders can be engineered to perform in any type of climate. Responsible asphalt rubber binder designers usually consider climate conditions and available traffic data in their design to provide a suitable asphalt rubber product. At intermediate and high temperatures, Asphalt rubber binder's physical properties are significantly different than those of conventional paving grade asphalts. The rubber stiffens the binder and increases elasticity (proportion of deformation that is recoverable) over these pavement operating temperature ranges, which decreases pavement temperature susceptibility and improves resistance to permanent deformation (rutting) and fatigue (Caltrans, 2003).

However, despite the proven advantages of AR hot mix asphalts, as clearly reported in the last four international Asphalt Rubber conferences (Sousa *et al*, 2000-2009), and elsewhere, there is still no breakthrough or significant development in the global practical use and implementation of this technology. Some reasons of this stagnation can be listed as follows:

- The tedious wet process of producing the Asphalt Rubber Binder, involving very high temperature (over 190°C) and long blending and reaction time (45 min. up to one hour).
- The complexity and cost of the blending unit that must be installed in every asphalt mixing plant.
- The necessity to re-heat the hot asphalt rubber binder after longer rest periods.
- The high cost of the Asphalt Rubber paving mixes as compared to conventional HMAs (ranges between 20-100% higher price).

In view of the proven advantage of AR technology, an effort was made to overcome the main disadvantages listed above. One solution that was found to provide a basis for an innovating and improving Asphalt Rubber is the new "Reacted and Activated Rubber" – RAR

2. The "Reacted and Activated Rubber" – RAR

2.1 General

The new Reacted and Activated Rubber (industrially known as RuBind), as an **Asphalt Rubber Binder**, is composed of plain soft bitumen, fine crumb rubber, and an Activated Mineral Binder Stabilizer (AMBS) at optimized proportions. RAR is produced by a short-time hot blending and activation in a specially designed process to form a dried granulated activated rubber.

RAR can be added to any type of Hot Mix Asphalt (HMA) – Dense, Open Graded, Gap-graded, SMA, etc., for replacing part of the asphalt cement (bitumen) at different proportions. In the mixing plant RAR is added directly to the pug mill or dryer drum, right after the bitumen spraying, using existing feeders (i.e. fiber feeders for SMA mixes, etc.).

Extensive R&D Research has shown that Asphalt Rubber HMA, produced with RAR, outperforms conventional HMA and even common modified and asphalt rubber mixes. In general, RAR is an **elastomeric asphalt extender** that modifies the plain bitumen by increasing its PG grading, resilience, and recovery properties. Different types of HMA produced with RAR showed much better Stability, Rutting and Fatigue resistance under attractive cost/benefit conditions.

2.2 RAR Composition

As seen in Figure 1, RAR is composed of soft asphalt cement (bitumen), fine crumb tire rubber (usually #30 mesh) and an Activated Mineral Binder Stabilizer (AMBS) at optimized proportions. A brief description of the ingredient is as follows:



Figure 1: RAR ingredients: Asphalt Cement (Bitumen), Crumb Tire Rubber and AMBS

The asphalt cement can be straight run plain soft bitumen. Asphalt cements or bitumen graded as Pen 100-200 to Pen 35/50, or AC 20, or PG 52 to PG 70, are used. The use of the softer bitumen enable to produce HMAs at common mixing and laying temperatures without losing the proper workability, despite the addition of the crumb rubber.

The Crumb Rubber is usually consisting of scrap tires that are processed and finely ground by any proven industrial method. The scrap tires consist of combination of automobile tires and truck tires, and should be free of steel, fabric or fibers before grinding. For the production of RAR, the crumb rubber particles should be finer than 1.0 mm. A #30 mesh maximum particle size is preferred. Cryogenic or ambient ground crumb rubber can be used.

The Activated Mineral Binder Stabilizer (AMBS) is a new micro-scale binder stabilizer that was developed to prevent excessive drainage of the bitumen in SMA mixes during mix haulage, storage and laying. This stabilizer (industrially known as “iBind”) is an activated micro-ground raw silica mineral (40 μm and finer), which is a waste by-product of Phosphate Industries mining. The activation, made by Nano monomolecular particle coating, was aimed at obtaining Thixotropic and Shear-Thinning properties for the bitumen, since the mastic in the mix should possess high viscosity at rest (haulage, storage and after laying) - for reducing draindown, and low viscosity in motion (mixing and laying) - for maintaining the proper workability (Ishai *et al*, 2011).

In global laboratory studies (made in Israel, Austria, Portugal, Sweden, China, Russia and the USA) it was found that SMA mixes, combined with the new micro-nano bitumen stabilizer, exhibit low acceptable bitumen draindown values which are comparable to those with fibers. Using systematic mix designs, European and American standard SMA mixes also show comparable to better mechanical properties relating to: water damage resistance, wear resistance, indirect tensile strength, rutting and fatigue resistance. These results were obtained with 0.5%-1.2% lower binder content and a 10-40°C lower mixing temperature, compared to the fibers (CONSULPAV, 2010; JSTRI, 2010; Smith, 2010; Watson & Moore, 2011; Ishai *et al*, 2011, Sousa, *et al*, 2012; Ishai *et al*, 2012). The reduction of mixing and compaction temperatures can classify the AMBS mix as a warm SMA mix – WSMA (Svechinsky *et al*, 2011).

Tests on Superpave mixes have shown that by replacing part of the bitumen binder with the AMBS stabilizer (up to 15%), improvement of mix properties (such as fatigue,

rutting and water damage resistance) was obtained (Wu *et al*, 2012). In this application it was found that the AMBS bitumen stabilizer also promotes the structural capacity of the binder and the HMA.

In addition to the engineering advantages, an analysis of the environmental benefits was performed. Generally, the comparison of the environmental indicators analyzed, clearly demonstrate a quantitative decline in the negative environmental indicators, as well as, the economic cost per ton SMA mix, when using AMBS as compared to cellulose fibers in SMA or regular dense and Superpave mixes (Ben-dov & Gingold, 2010).

During the 2010 and 2011, two comparable road tests were successfully performed in Israel. The behavior of the test sections so far, validated the positive laboratory results obtained hitherto, relating to AMBS SMA mixes (Ishai & Svehinsky, 2011).

2.3 RAR Production

At this stage, from the beginning of 2012 until the final writing of this paper, the Reacted and Activated Rubber has been produced in pilot production units. During the R&D work, RAR was produced and tested at different formulations, dictated by the type and relative proportions of its three components. As an average, a typical RAR blend contains about 62% Crumb Rubber, 22% soft bitumen, and 16% AMBS. For the final coating of the basic RAR after cooling, additional 10% AMBS is added in the coating mixer.

3. Suggested Basic Model and Mechanism

As stated above, the Reacted and Activated Rubber (RAR), is an innovating and improved elastomeric extender that was found to enhance the properties of the plain bitumen up to higher levels than polymer modified asphalt, and even higher than conventional asphalt rubber blends. A suggested basic model for the mechanism of RAR as a bitumen enhancer is illustrated in Figure 2, and explained as follows:

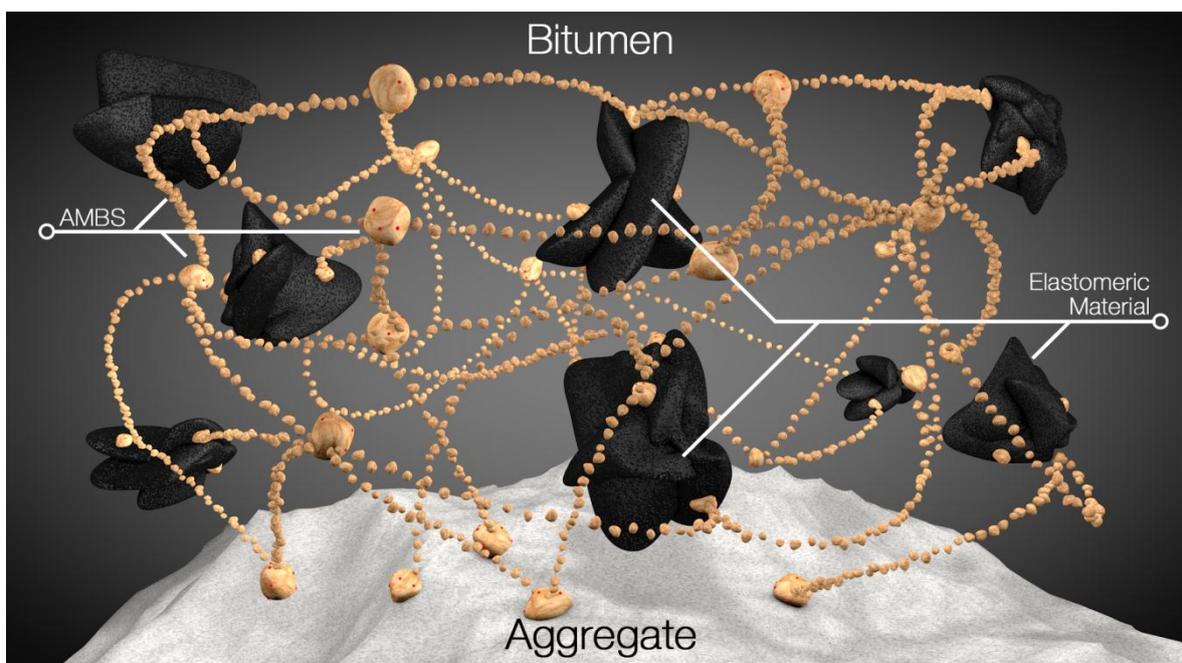


Figure 2: A suggested model for the mechanism of RAR as an asphalt extender

Crumb rubber particles contains large amount of inorganic materials that are electro-statically surface charged (fillers, vulcanization materials, and various additives). The activator of the silica mineral particles of the AMBS is composed of organic molecules that are partly electro-statically surface charged (ammonium head) and contains organic hydrophobic chains. When the activator particles are present in a liquid medium (bitumen), they can be attracted and connected to other particles with opposite charge.

Charged organic chains of the activator in the AMBS are able to create a connected network of particles. When the fine RAR particles (elastomeric material) are blended in the liquid medium with the activated silica particles, then charged molecules of the AMBS particles are connected to the rubber particles in charged places of the inorganic materials. In this way, where all the above materials are blended together with the hot liquid bitumen, an inner network of the elastomeric material and the AMBS particles is formed in the bitumen. This network, together with the unique elastic and networking capabilities of the elastomeric material derived from the reaction and activation of rubber at high temperatures, structurally enhance the bitumen with better mechanical properties, better elastic behavior, and better long term performance. RAR is also coated with a special formulation of AMBS that once dispersed into the bitumen also attaches itself to the aggregate. This connection improves binder aggregate interactions improving moisture sensitivity responses. As such the new networks bound aggregate, bitumen, elastomeric material and AMBS particles. Such a network cannot be formed when just rubber and bitumen are blended together (without AMBS), as in any conventional Asphalt Rubber technology.

4. Properties and Behavior of RAR as Asphalt Rubber Binder

In the R&D stages of the Reacted and Activated Rubber, extensive testing effort was dedicated to characterize the properties and behavior of the new Rubber Binder. Since RAR is intended to replace part of the non-modified bitumen in the HMA mix, the physical and rheological properties of the combined binder (RAR + Bitumen) was studied at variable proportions of RAR in the original bitumen content of the mix, depending on the HMA type, such as: Dense, SMA, Gap-graded, and Open Graded mixes, etc. (Sousa & Silva, 2012).

Table 1 and Figure 3 present the results of basic and conventional asphalt binder tests performed on two RAR formulations TA and TA2. The Viscosity, Softening Point, Penetration, and Resilience were evaluated as a function of RAR content in the total combined binder.

Table 1: *Properties of the combined binder as a function of RAR content in it*

| RuBind | % RAR | Viscosity | Ring and Ball | Penetration | Resilience | Date |
|--------|-------|-----------|---------------|-------------|------------|------------|
| TA | 10 | 250 | 56 | 38 | 11 | 14-03-2012 |
| | 15 | 350 | 56 | 38 | 14 | |
| | 20 | 650 | 57 | 36 | 22 | |
| | 25 | 1150 | 59 | 34 | 25 | |
| | 30 | 2200 | 62 | 30 | 27 | |
| TA2 | 0 | 115 | 54 | 46 | 7 | 12-03-2012 |
| | 10 | 250 | 55 | 40 | 11 | |
| | 15 | 325 | 56 | 37 | 17 | |
| | 20 | 450 | 59 | 35 | 25 | |
| | 25 | 1012 | 63 | 27 | 30 | |
| | 30 | 2800 | 70 | 22 | 38 | |

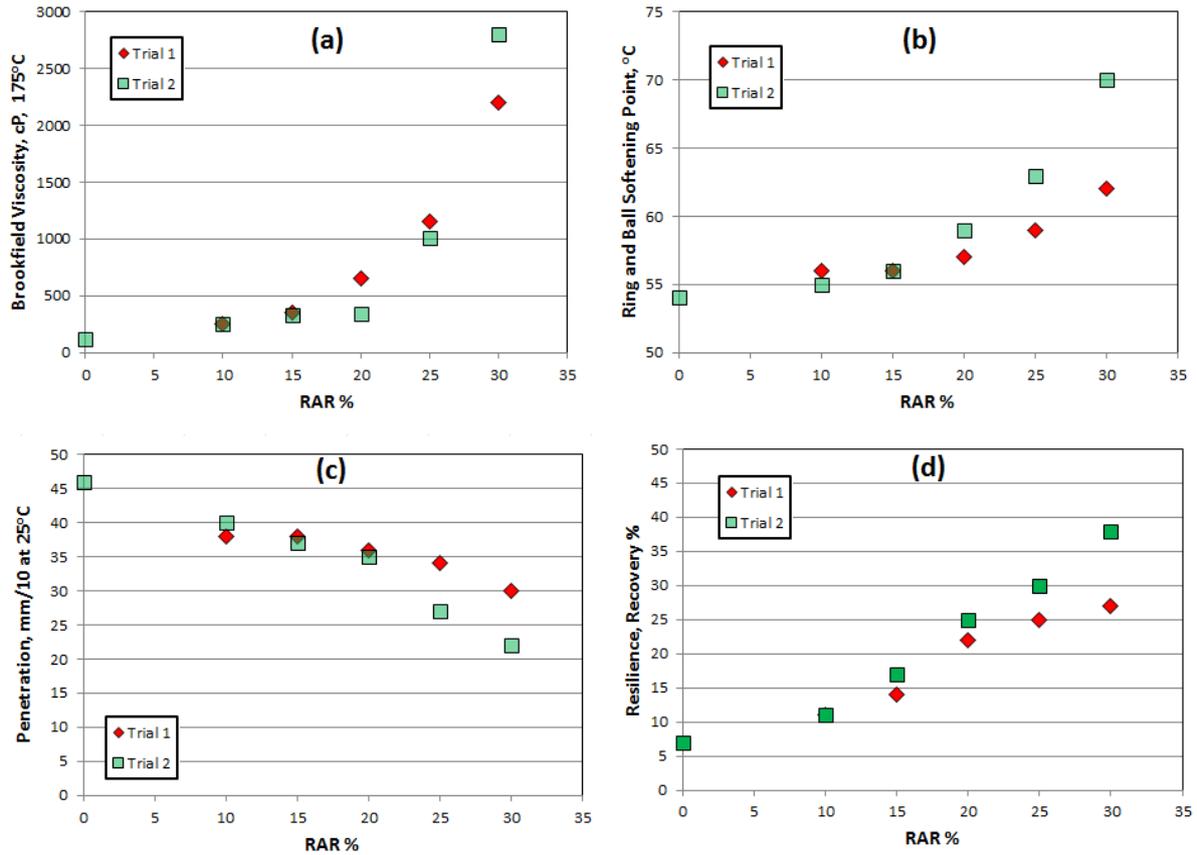


Figure 3: Traditional binder properties, a) Viscosity, b) Ring and Ball Softening Point, c) Penetration and d) Resilience

It can be seen that the proportion of the RAR in the combined binder, has a significant effect on its basic properties in increasing viscosity, softening point and resilience, and in decreasing penetration of the combined binder. This will play an important role in the different types of hot mix asphalts.

As for the rheological behavior of asphalt binders in HMA, as usually tested by a Dynamic Shear Rheometer (DSR), the effect of RAR content in the combined binder can be studied through the change of its PG grading, as shown in Figure 4 and 5, for the plus and minus grading indicators, respectively.

As can be seen, the addition of RAR to non-modified bitumen upgrades significantly the rheological behavior of the bitumen. This is reflected by the increase of the positive PG grading indicator and decrease of the negative indicator, as a function of increasing the RAR proportion in the combined binder. This effect is similar to the addition of polymer modifiers to plain bitumen to get modified asphalt binders. It should be stressed that with the addition of the RAR to the plain bitumen, the presence of the crumb rubber and the enhancing network created by the AMBS, provide combined bitumen with much better elastic properties.

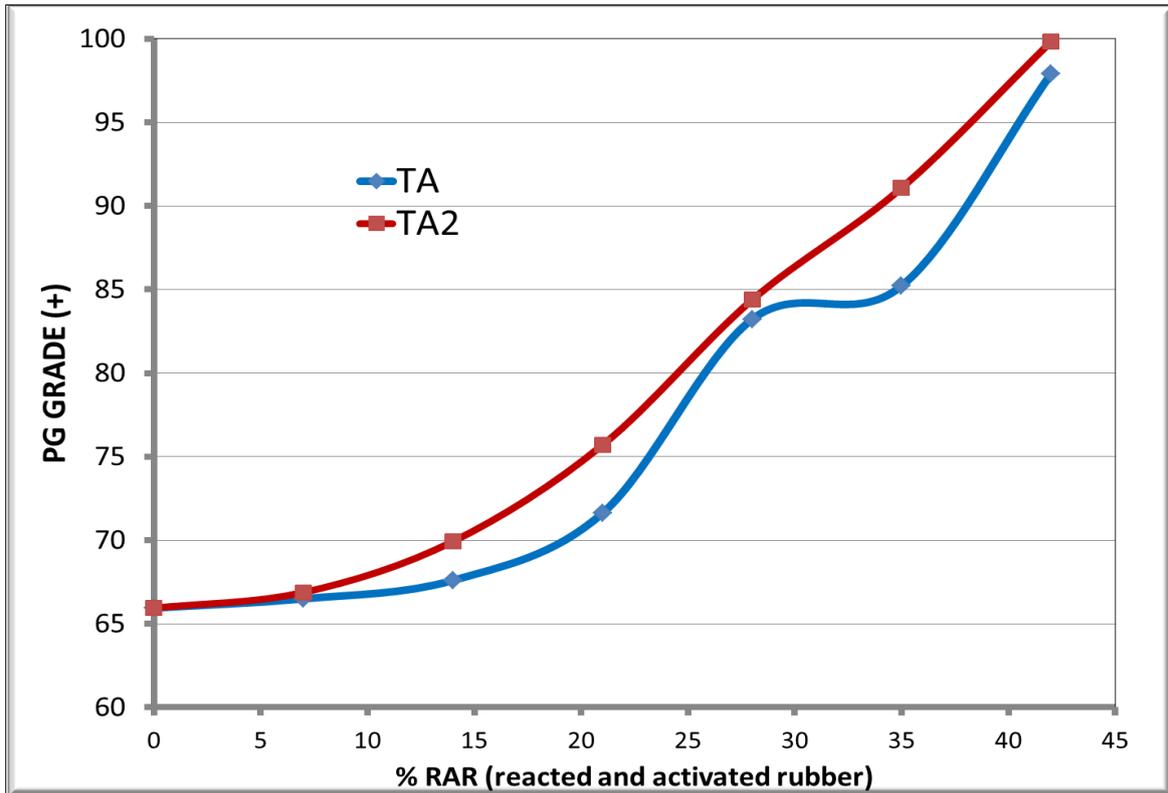


Figure 4: Effect of %RAR on the PG grading of the combined binder (positive indicator)

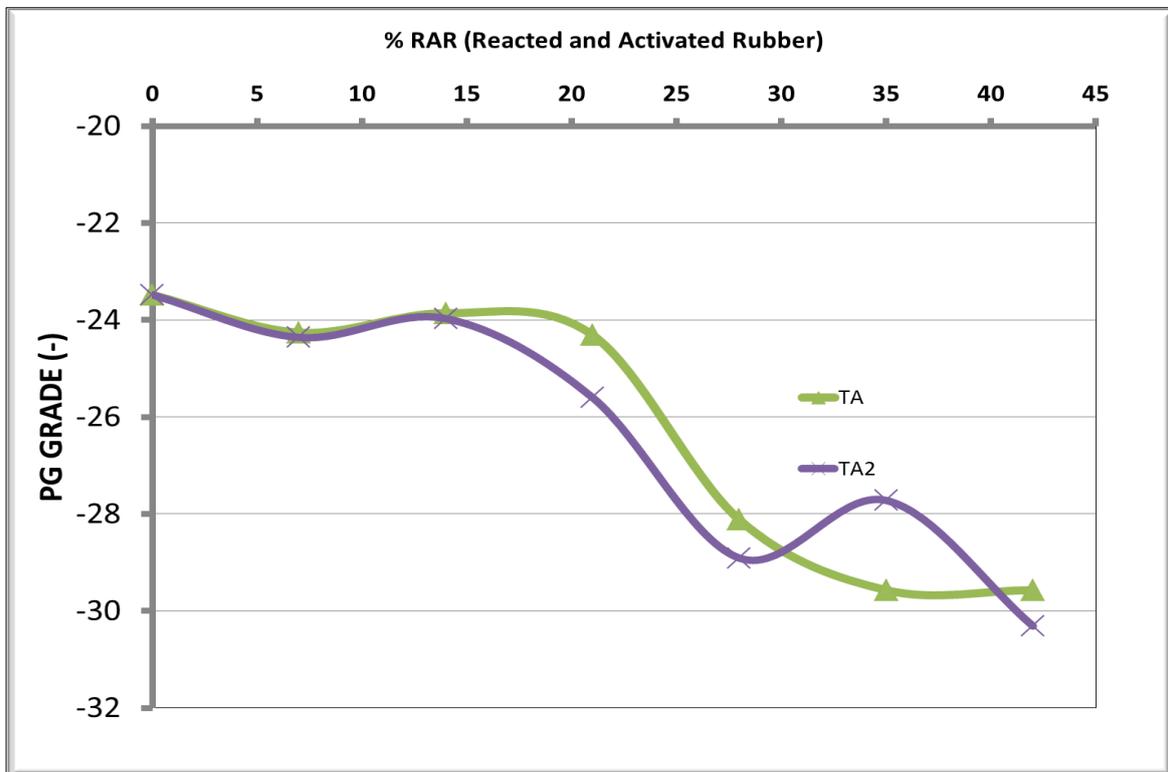


Figure 5: Effect of %RAR on the PG grading of the combined binder (negative indicator)

Similar results and trends with respect to the influence of RAR on upgrading the rheological behavior of the bitumen were observed during an extensive study on Russian bitumen (Sousa, 2012). As can be seen in Figure 6, the addition of 21% percent RAR to the plain bitumen with positive PG grading of PG64 to PG70 create the increase up to PG88 to PG94. This exhibit significant modification of the bitumen, as conventionally achieve by Polymer modification.

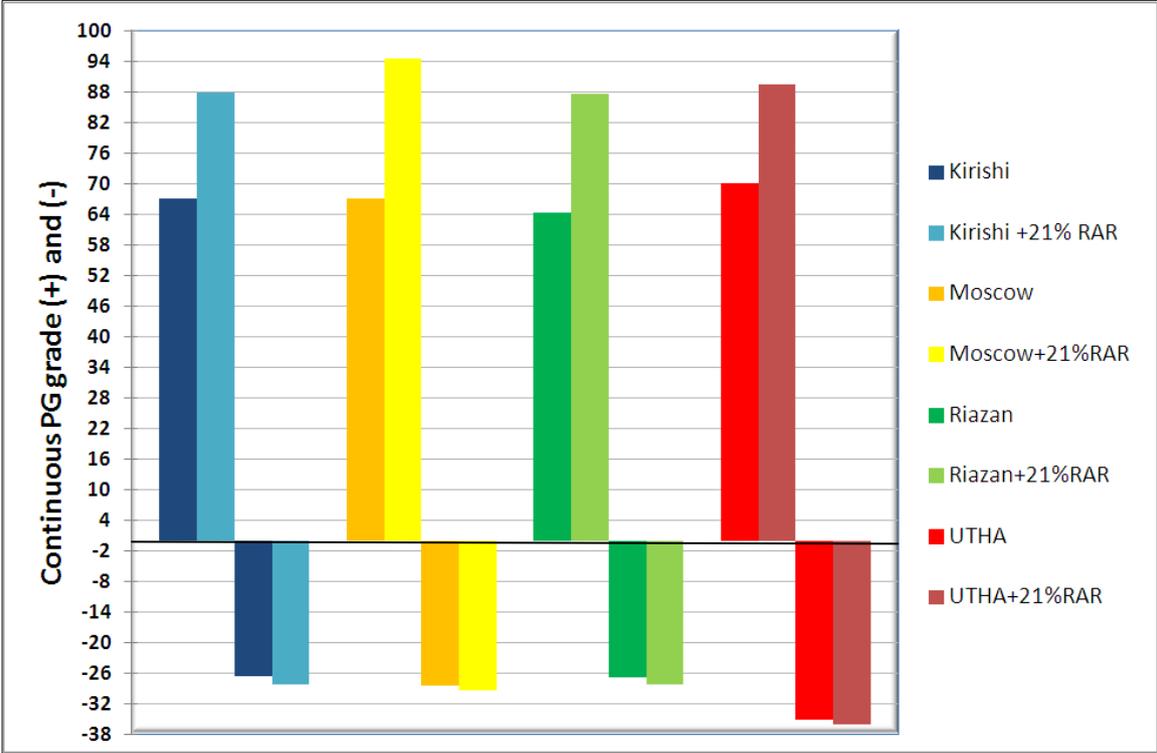


Figure 6: Effect of RAR addition on the PG grading of the combined binder (negative notation) as studied on Russia bitumen

The replacement of part of the bitumen in HMA with RAR was also found to have a significant effect on the recovery properties of the combined binder. It is possible to study the effect of RAR content on the recovery properties of the combined binder using the conventional recovery analysis and also with the new JNR concept. This concept, which is based on the Multi Stress Creep Recovery (MSCR) AASHTO TP 70, gives an indication of the quality of the binder in order to resist permanent deformation and generally to be able to recover from deformation. The results of the recovery analyses are presented in Figs. 7 and 8.

As also shown by the results, the addition of RAR to the non-modified bitumen improves significantly the recovery ability of the bitumen. This is reflected by the increase of the recovery magnitude or the decrease in the JNR values, as a function of increasing the RAR proportion in the combined binder.

Again, similar results and trends with respect to the influence of RAR on the exceptional recovery ability of RAR-bitumen binder were observed during an extensive study on Russian bitumens (Sousa, 2012). This is shown in Figure 9. As can be seen, the additions of 21% percent RAR to the plain bitumen significantly increase the recovery potential of the new binder. This is reflected by the very low JNR values of the RAR-bitumen binder that re-classify the bitumen to be suitable for "Extremely Heavy Traffic".

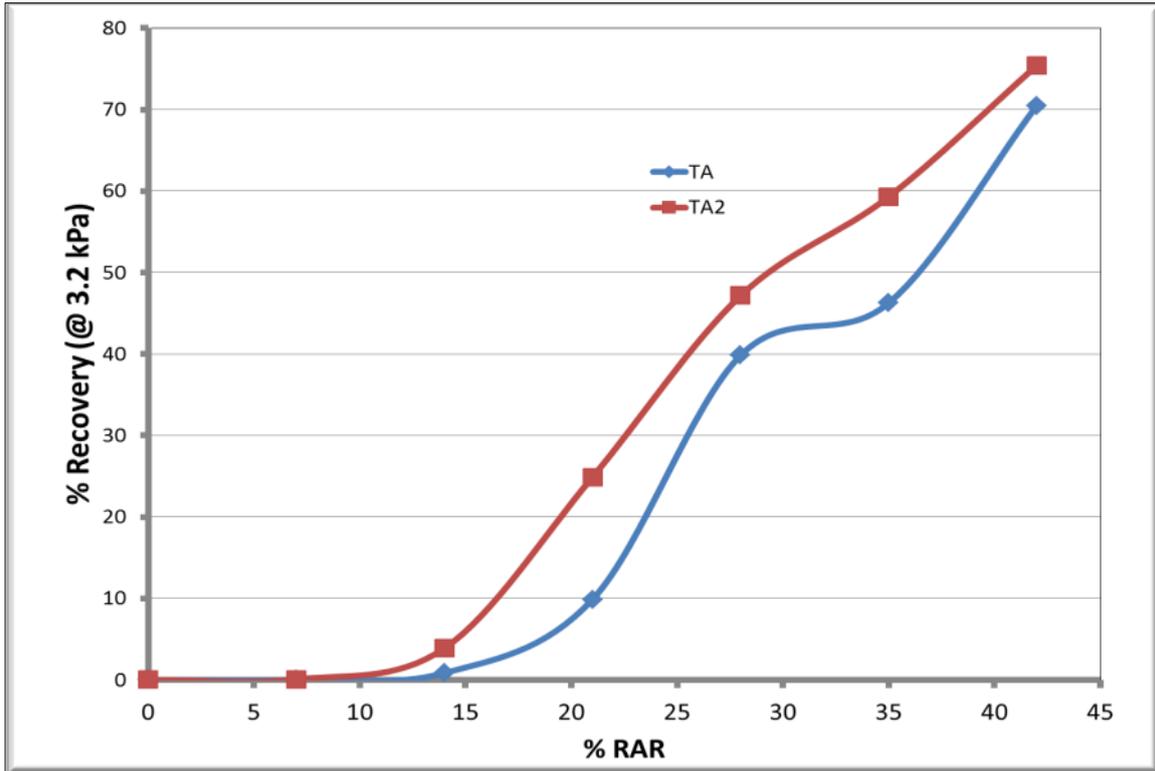


Figure 7: Effect of %RAR on combined bitumen recovery as tested by the conventional method

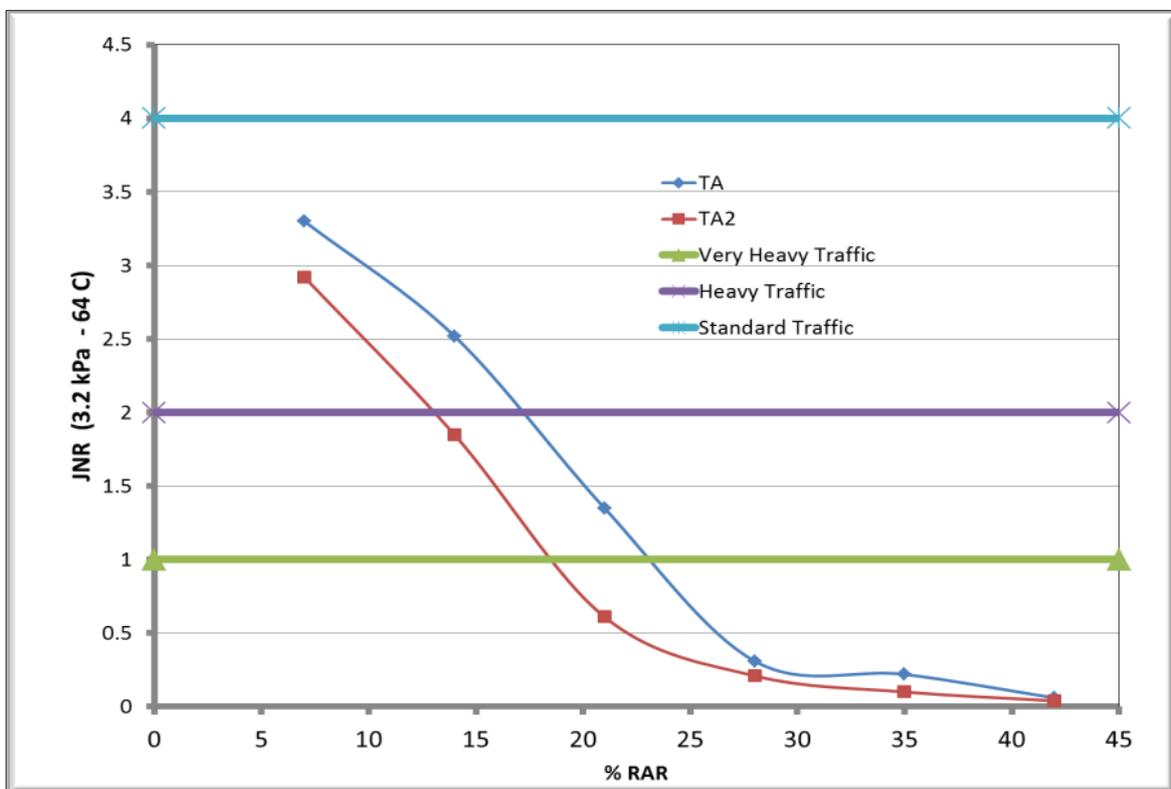


Figure 8: Effect of %RAR on combined bitumen recovery expressed by the JNR concept

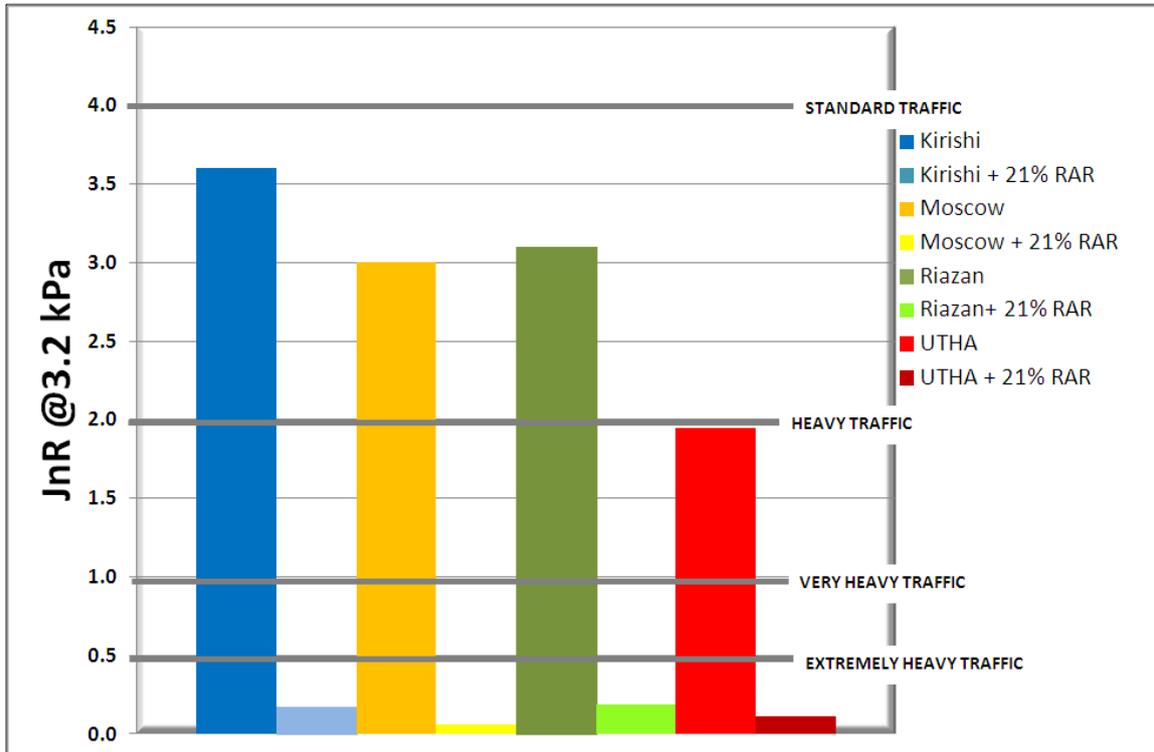


Figure 9: *Effect of RAR addition on the recovery potential of the combined binder (expressed by JNR) as studied on Russia bitumens*

5. Properties and Behavior of HMA mixes Composed with RAR

As stated above, RAR is used to replace part of the non-modified bitumen in HMA for paving. During the R&D stages, the physical, mechanical and long term properties and behavior of HMA, composed of combined binder (RAR + Bitumen), was studied. This was done at variable proportions of RAR in the original bitumen content of the hot mix asphalt, depending on its type, such as: Dense, SMA, Gap-graded, and Open Graded mixes, etc. The following are typical examples of test results:

During the routine Marshall mix design of typical dense HMA, it was found that the absolute magnitudes of stability are much higher than in conventional asphalt mixes. As shown in Figure 10, in the dense mix optimum stability was obtained at 20% RAR content within the combined binder. A relative very high value of optimum stability was recorded (18,000 N, or 4,050 lb.), associated with standard flow values. It means that the RAR strengthened the mix substantially without rigidifying it.

Marshall tests were also performed on Russian SMA mixes with four types of local binder combinations (Sousa, 2012). Two mixes (at 6.2 bitumen content) were made with strong polymer modification (SBS and Bitract), while other mixes with a soft bitumen (Riazan) were stabilized first with 0.4% fibers (6.5 percent of the bitumen), and also with 30% RAR in the combined binder. Marshall stability results are shown in Figure 11 and Draindown test results in Figure 12.

In this case it can also be seen that the SMA mix made with RAR outperformed all other mixes with respect to the Marshall stability, and also with respect to the ability to prevent bitumen draindown from the mix at rest periods prior to compaction.

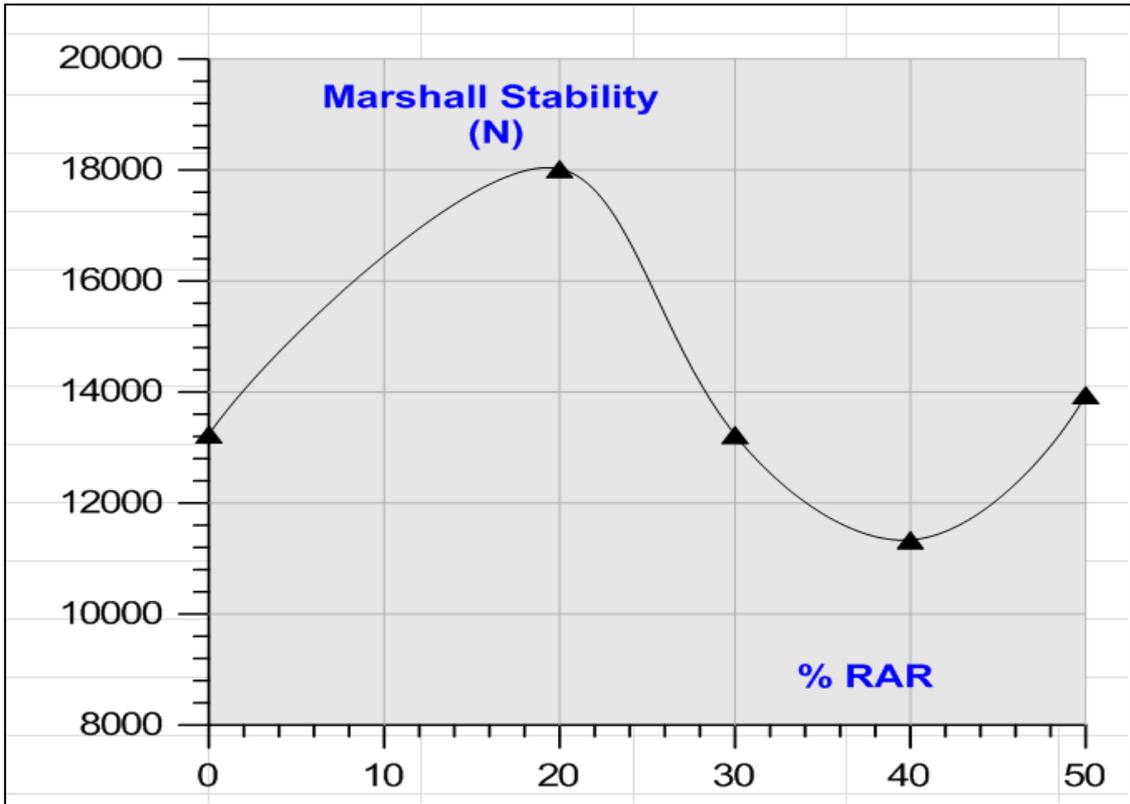


Figure 10: Marshall Stability of dense HMA as a function of RAR content in the combined binder

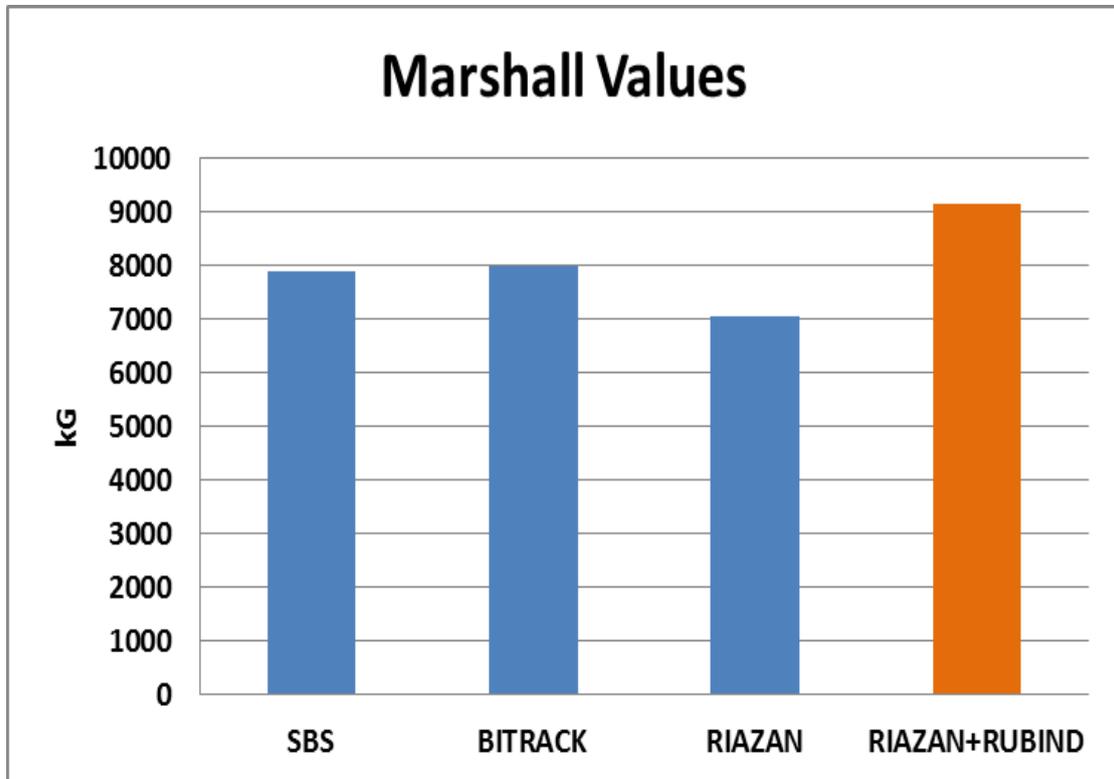


Figure 11: Average Marshall stability results obtained in four Russian SMA mixes

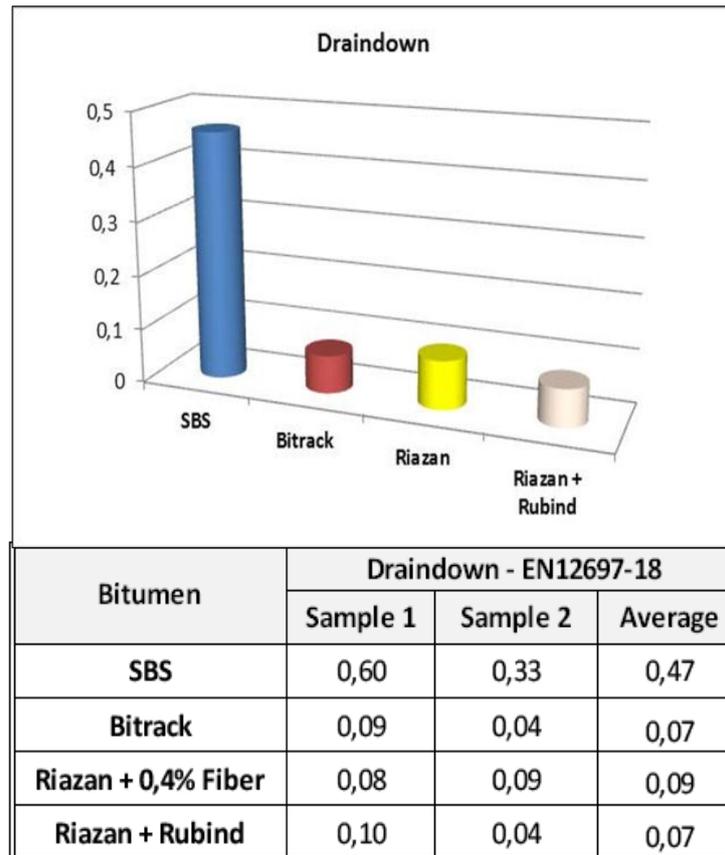


Figure 12: Draindown test results obtained in four Russian SMA mixes

Consequently, it shows that the RAR asphalt rubber binder can also serve as an efficient binder stabilizer for SMA mixes that can replace the tedious use of cellulose fibers. Similar draindown results were obtained in Israeli SMA mixes with 15-25% RAR contents, as can be seen in Table 2.

Table 2: Draindown test results obtained in an Israeli typical SMA mix with RAR

| Draindown Tests on SMA mixes with RAR (Dimona, May 14, 2012) | | | |
|---|---|-------------|-----------|
| Type of RAR | Produced at DSI Dimona, May 2 nd , 2012 Batch #3 | | |
| Bitumen | PG 70-22, Haifa Refineries | | |
| Aggregates | Fine – Dolomite, Coarse - Basalt | | |
| SMA Mix | SMA 12.5 mm, Israeli Standard, 6.0 Bitumen Content | | |
| Gradation | Coarse gradation near lower limit | | |
| Mixing and Draindown Temp. | 170°C | | |
| (Bitumen+RAR) in Mix (%) | 6.0 | | |
| % RAR in (Bitumen+RAR) | 15 | 20 | 25 |
| % Bitumen in Mix | 5.1 | 4.8 | 4.5 |
| % RAR in Mix | 0.9 | 1.2 | 1.5 |
| % Draindown EN 12697 (Schellenberg Beaker) | 0.03 | 0.01 | 0 |

Rutting tests were performed on different SMA mixes, comparing conventional mixes with fibers and plain AMBS (as binder stabilizers) to different formulation of GAP GRADED (ADOT curves) mixes with RAR . Results are shown in Figure 13:

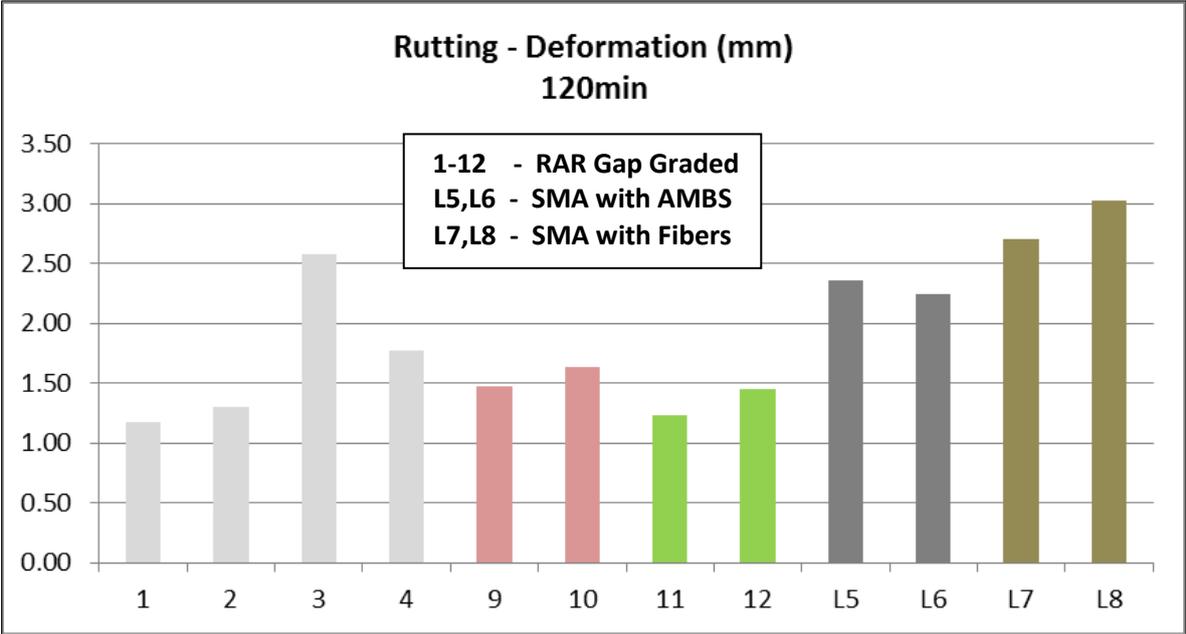


Figure 13: Rutting results on GAP Graded mixes, comparing RAR mixes to SMA mixes

As can be seen, Gap Graded mixes that contain RAR, exhibit much lower rutting, as compared to the SMA ones. The averages rutting magnitudes are 1.58 mm rut depth vs. 2.58 mm, respectively. By omitting the deviated result of mix no. 3, the values are 1.38 mm rut depth vs. 2.58 mm. That means that the conventional SMA mixes have rutted 87% more than the RAR GAP Graded mixes.

Extensive flexural fatigue tests, using the 4 Point Bending Beam device (AASHTO T321) were performed on variety HMA mixes. Tests were made on Polymer Modified SMA mixes, Gap Graded conventional Asphalt Rubber mixes, and Dense Graded mixes, as compared to RAR Gap Graded mixes. Several RAR Gap Graded mixes were formulated having the same binder content and add mix content as the reference AR-GAP A mix. The reference AR GAP A Graded mix had 8.23% AR Binder and 1% Portland cement or hydrated lime. As such the total additive content to that gap graded mix was 9.23%. RAR GAP graded mixes were formulated such that the sum of regular unmodified binder plus the RAR would add up to the same amount of 9.23%. They were B6.19RAR3.04 (representing bitumen content of 6.19% and RAR content of 3.04%), B5.45RAR3.78 and B4.71RAR4.52. With about 62% crumb rubber in the RAR it can be easily computed that the mixes had about 20%, 25% and 30% of crumb rubber in terms of the total 9/23% of binder.

The 4 Point Bending Beam flexural fatigue test results are presented in Figure 14 (tests were executed under displacement control at 10 Hz, 20 °C and 500 microstrain). It can be seen that the RAR Gap Graded mixes outperform all other mixes tested, moreover the mix with 49% RAR in the combined binder (i.e B4.71RAR4.52), has a fatigue life that is about 7 times longer than the conventional Asphalt Rubber gap graded mixes.

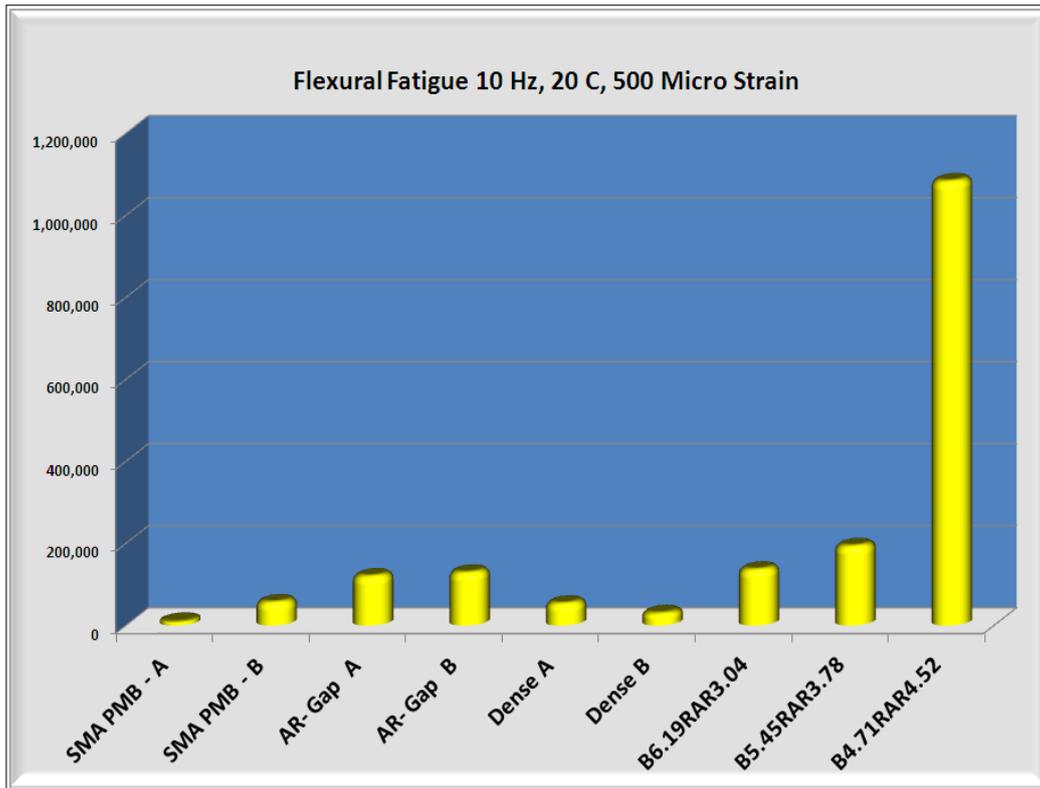


Figure 14: Flexural Fatigue test results on different HMA mixes comparing to RAR ones

Recovery tests on RAR HMA mixes were made using simple Marshall cylinders, one day after the stability test (see Figure 15). Following initial pressing down and measurement with the top cover, the sample was left at rest for 24 hours at 20° C. Afterwards, measuring the lift up of the top cover indicated a recovery of 15.35-12.43=2.92 mm. This is a radial recovery of 2.9 mm which is quite substantial for asphalt paving mixes. The recovery of the asphalt rubber binder itself is much higher, as was seen for example in Figure 7.



Figure 15: Recovery measurement on RAR HMA mixes using the Marshall setup

Recovery observations on RAR Gap Graded mixes (with 9% binder content) were also made after performing a rutting test. Results are shown in Figure 16:

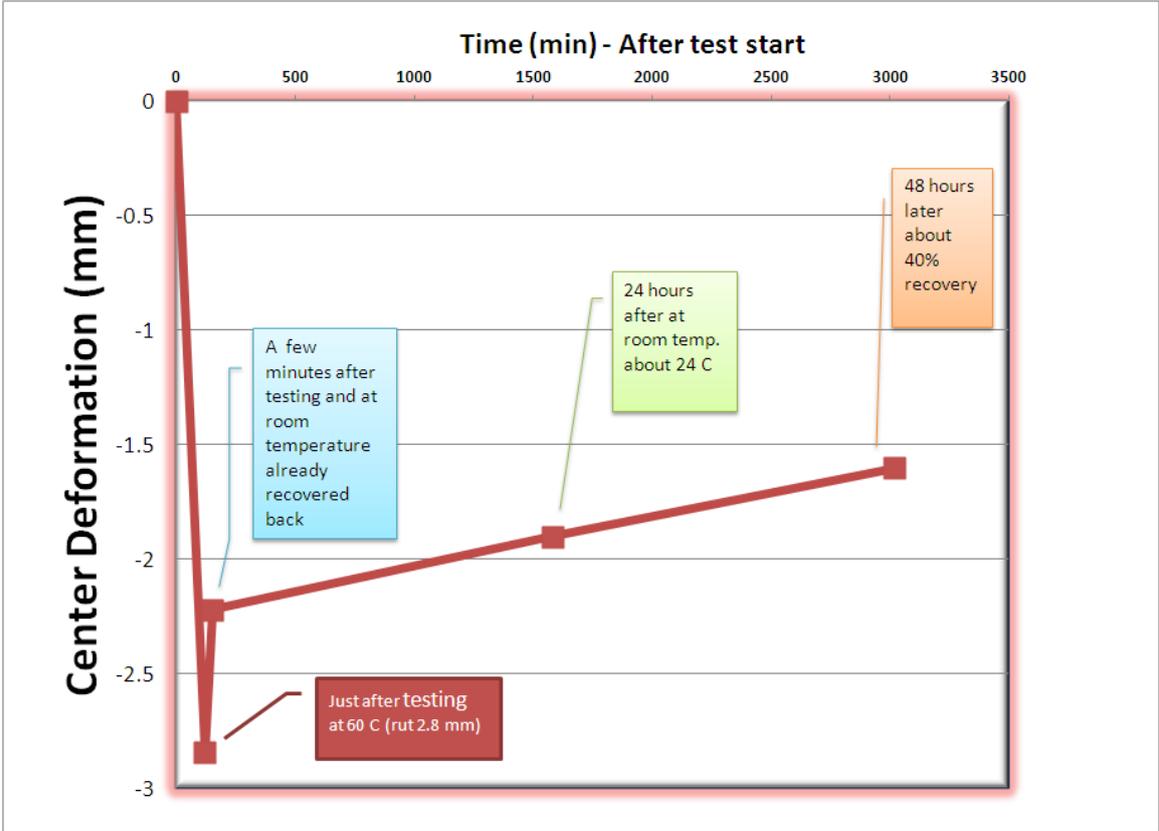


Figure 16: Recovery observation on RAR Gap Graded mixes after a rutting test

Deformations were measured at the center of the slab, after a total rutting of 2.8 mm was reached (test run at 60°C for 2 hours). As can be seen, an immediate recovery of more than 0.6 mm was obtained (about 21%). Furthermore, the recovery continued up to more than 40% of the total rutting deformation, as measured after 40 hours.

6. Some Logistical and Technological Aspects

Since the crumb rubber is the largest component in the RAR composition (more than 60% by weight), it is logistically recommended to install the RAR production unit within the tire processing plant domain. The other two ingredients (bitumen and AMBS) will be imported from their sources, while the final RAR product will be exported directly to the asphalt mixing plants.

As different from the common asphalt rubber binder, the industrially prepared RAR (which comes in dry granulated form), can be fed directly to the pugmill or the dryer drum of any asphalt mixing plant. The common auxiliary feeders used in any asphalt plant are adequate (see Figure 17).

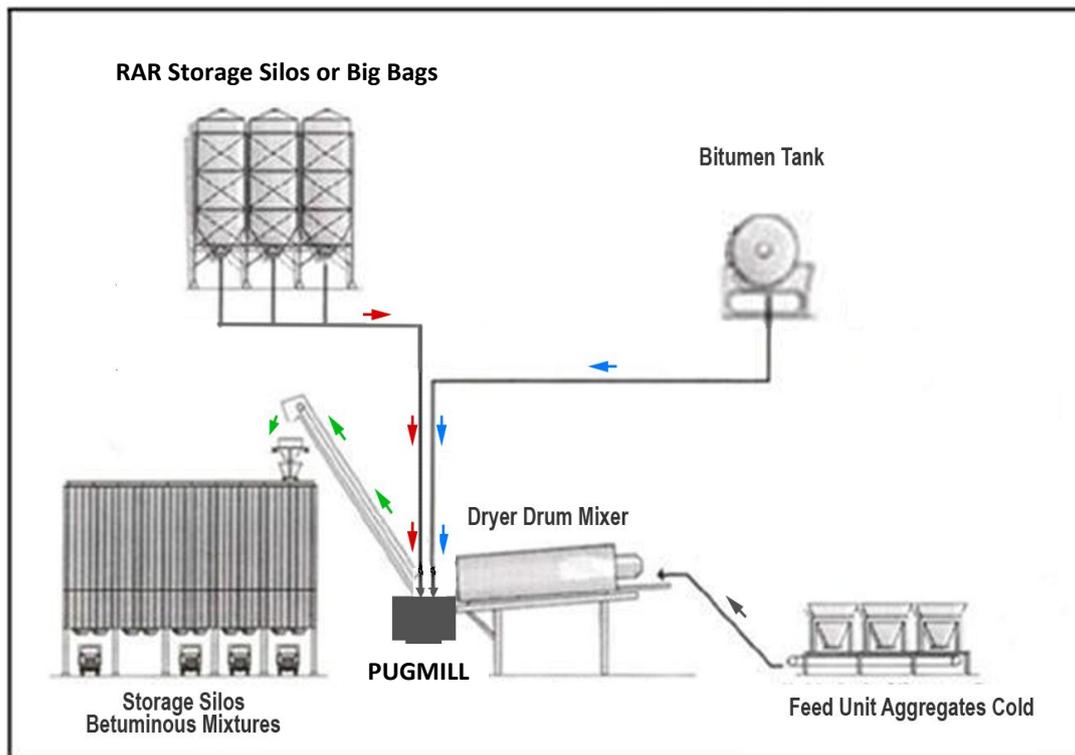


Figure 17: RAR can fed directly to the pugmill or dryer drum of any asphalt mixing plant using the existing common auxiliary feeders

RAR should be added to the asphalt mix, in laboratory or mixing plant, after the bitumen is applied to the mixer - First mix aggregate and filler, then add the plain bitumen (AC), and after the bitumen has well coated the aggregate, add the RAR. Then complete the mixing cycle about 30 second more, until the RAR has evenly distributed and absorbed by the bitumen.

Mixing temperature of RAR asphalt mixes is identical to that of the mixes it replaces (usually about 170 °C to 180 °C). However if high RAR contents are used (such as, for example 3.5% in gap grade asphalt rubber mixes) then maybe the aggregates should have a slightly higher temperature so that the mix quickly reaches the mixing temperature. In laboratory, before compaction, the mix of RAR, bitumen and aggregate must stay in the oven for 1 hour at 170° C. This simulates the time it usually takes between mixing in the plant and compaction in the field. During this time RAR coatings are activating the bitumen and aggregate surfaces.

RAR improves binder qualities. From this perspective, the higher percentage of RAR used the better. This can be clearly observed in the discussion and figures of section 5 above. Real significant improvements in binder properties can be seen when the RAR percentage in the combined binder is above 15%. However, there is a point after which there is not enough plain bitumen to coat the aggregates, or the viscosity becomes too high. That will cause the increase of mix air voids and VMA after compaction, beyond acceptable ranges. This also may create partially coated aggregates.

Experience has shown that there should always be at least about 4% of plain bitumen (by weight of the total mix) in all mixes, to allow aggregate coating and sufficient workability. As such, the difference to regular binder contents can be replaced by RAR. As an example, if in an SMA the mix design requires 6% bitumen content, then in a RAR mix

design it would be expect to see 4% of whatever regular binder is used, and about 2% of RAR (that is 33% of the combined binder). In a dense graded mix, with regular binder content of about 5%, then a 4% regular bitumen and about 1% RAR can be considered. The base 4% binder content also depends on the mix gradation. This is probably more valid when mixes are used on the coarse side of the gradation envelop. If mixes are used on the fine side of the gradation this reference value should increase. In any case, the optimum combined binder content (bitumen + RAR) should be determined according to any one standard mix design.

As a general guidance, the following are the RAR content in the combined binder and the total mix, for the different types of HMA mixes:

- In Dense Graded mixes – 20% of the combined binder or 1% of the total mix.
- In SMA mixes – 30% of the combined binder or 2% of the mix.
- In GAP Graded mixes – 40% of the combined binder or 3-4% of the mix.
- In OPEN Graded Friction courses – 50% of the combined binder or 4 to 5% of the mix.

When using RAR asphalt mixes, no other additives are required (no fibers, no polymer modifier, etc.). This is because it was formulated to improve adhesion, fatigue and rutting resistance when compared to an identical mix without RAR. On the other hand, when considering warm mixes, an adequate additive could be experimented with.

7. Summary and Major Advantages

As described in the paper, the new Reacted and Activated Rubber - RAR (industrially known as RuBind), is an innovative and improved Asphalt Rubber Binder. It is composed of plain soft bitumen, fine crumb rubber, and an Activated Mineral Binder Stabilizer (AMBS) at optimized proportions. RAR is produced by a short- time hot blending and activation in a specially designed process to form a dried granulated Asphalt Rubber Binder.

RAR can be added to any type of Hot Mix Asphalt (HMA) – Dense, Open Graded, Gap-graded, SMA, etc., for replacing part of the asphalt cement (bitumen) at different proportions. In the mixing plant it is added directly to the pug mill or dryer drum, right after the bitumen spraying, using existing feeders (i.e. fiber feeders for SMA mixes, etc.).

Tests performed during the R&D stage, has shown that Asphalt Rubber HMA, produced with RAR, outperforms conventional HMA and even regular modified and asphalt rubber mixes. In general, RAR is an **elastomeric asphalt extender** that modifies the plain bitumen by increasing its PG grading, resilience, and recovery properties. Different types of HMA produced with RAR showed much better Stability, Rutting and Fatigue resistance under attractive cost/benefit conditions.

The following are the main advantages of RAR as an asphalt rubber binder in hot asphalt rubber mixes (as mainly compared to the common Asphalt Rubber technology):

- Easy and fast production. No need for AR or modifier blenders.
- No more re-heat cycles in the asphalt mixing plant or job site.
- The RAR product is a dry granulated material – easy to handle, store and transport.
- Can be fed to any asphalt mixing plant directly to the pugmill or the dryer drum.
- When blended with the plain bitumen in the mixing plant, a unique asphalt rubber binder is formed to provide better resilience and recovery and higher viscosity and softening point.
- With increasing RAR content in the combined binder (RAR + Plain Bitumen) any PG Grade binder can be formed (both positive and negative PG grade indicators).

- With the correct RAR content, any type of hot AR mix can be produced (Dense Graded, SMA, Open Graded, Gap Graded, etc.).
- Can make new improved hot AR mixes (with even more crumb rubber) that are stronger more resilient, and exhibit better Recovery, Rutting and Fatigue resistance.
- RAR most efficiency can substitutes the tedious cellulose fibers in SMA mixes.
- Can create Warm Asphalt Mixes with the incorporation of proper warm mix additives.
- Environmental benefits by using higher proportions of crumb rubber (from recycling of scrap tires) and less energy spent during the production of Asphalt Rubber.
- Cost Effectiveness as compared to both conventional HMA and to regular Asphalt Rubber mixes.
- Now an improved Asphalt Rubber can be produced and implemented in every job, in any country.

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References

Ben Dov, O. and Gingold, G., "iBind - Activated Mineral Stabilizer for SMA – Environmental Indicators Comparison" Prepared For Dimona Silica Industries - DSI Ltd., ASSIF Strategies, August 2010.

CALTRANS – State of California Department of Transportation, Division of Engineering Services, Office of Flexible Pavement "Asphalt Rubber Usage Guide", MS#5, January 2003.

CONSULPAV – Consultores e Projectistas de Pavimentos, Lda, "Study of European SMA 11 and South Carolina SMA 12.5 with PG-76 Bitumen – iBind vs. Fibers" Study Realized for DSI Israel, Report EST 10-02, Lisbon Portugal, August 2010.

Ishai, I., Sousa J.B. and Svehinsky, G. "Activated Minerals as Binder Stabilizers in SMA Paving Mixtures" Compendium, 90th Annual Meeting of the Transportation Research Board – TRB, Washington DC, January 2011

Ishai, I., Svehinsky, G. and Sousa J.B. "Introducing an Activated Mineral as Innovative Binder-Stabilizer for SMA Paving Mixtures" Compendium, International Road Congress on Innovation in Road Infrastructures", International Road Federation – IRF, held in Moscow, Russia, November 2011.

Ishai, I. and Svehinsky, G. "A Road Test Comparing SMA Mixes with iBind vs. Cellulose Fibers – Overlaying of Access Road to the Revaya Quarry, Bet She'an Valley, Israel" Prepared for DSI – Dimona Silica Industries, August 2011.

Ishai, I., Svechinsky, G. and Sousa J.B. "A Micro Ground Mineral Activated by NANO Molecules as Binder Stabilizer in SMA Paving Mixtures", to be presented at the Second International Symposium on Asphalt Pavements & Environment. International Society of Asphalt Pavements (ISAP), to be Held in Fortaleza Brazil, October 2012.

JSTRI – Jiangsu Transportation Research Institute "The Test Report of Stone Mastic Asphalt Mixtures with iBind Additives", Prepared for DSI Israel, Report No. 011908098, Nanjing China, November 2010.

Smith, Mark, "Laboratory Report on the Evaluation of iBind as an Additive to Asphalt Mixtures" Akzo Nobel Surface Chemistry AB, Asphalt Applications, Stenungsund Sweden, Report No. 11007, May 2011.

Sousa, J.B. *et al* (Editors) – Proceedings, International Asphalt Rubber Conferences: AR2000 in Vilamoura, AR2003 in Brasilia, AR2006 in Palm Springs, and AR2009 in Nanjing.

Sousa, J.B. "Study of RuBind Stage 4 – Russian Bitumen", Realized for RuBind™. CONSULPAV – Consultores e Projectistas de Pavimentos, Lda, Casais da Serra, Portugal, June 2012.

Sousa, J.B. and Silva, F. "Development Studies Study of RuBind Stage 5 – PG Grade Evaluation TA and TA2 RuBind Formulations", Realized for RuBind™. CONSULPAV – Consultores e Projectistas de Pavimentos, Lda, Casais da Serra, Portugal, June 2012

Sousa J.B., Ishai, I., and Svechinsky, G. "Flexural Fatigue Tests and Prediction Models – Tools for Investigating SMA Mixes With New Innovative Binder Stabilizer" to be presented at the Third International Workshop on Four Point Bending (4PB), to be held in the University of California at Davis CA, September 2012.

Svechinsky, G., Ishai, I. and Sousa, J.B. "Developing Warm SMA Paving Mixes Using Activated Mineral Binder Stabilizers and Bitumen Flow Modifiers" Proceedings, the Second International Conference on Warm Mix Asphalt, St. Louis Missouri, October 2011.

Watson, D.E. and Moore, J.R. "Evaluation of SMA Mixture with iBind and Fibers" National Center for Asphalt Technology – NCAT at Auburn University, Alabama, Report No. 11-04, August 2011.

Wu, C., Sousa, J.B., Li, A. and Zhao, Z. "Activated Minerals as Binder Stabilizers in Middle Course's Asphalt Concrete Paving Mixtures", Compendium, 91th Annual Meeting of the Transportation Research Board – TRB, Washington DC, January 2012