REVIEW OF THE CHANGING WORLD OF CRUMB RUBBER WET AND DRY PROCESS

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ABSTRACT: *This review paper discusses both what happened with the crumb rubber dry and wet processes, and why the wet process in many different forms has been successful and not so historically with the dry process. In the dry process the scrap tire rubber particles act as rubber aggregates or filler of different sizes. The rubber particles are mixed with hot aggregate and asphalt in the hot plant and heated from 15 to 45 seconds and then dumped into a truck to be transported to the laydown machine. The limited time of heated interaction of the rubber particles and the asphalt is a possible inherent weakness of the dry process and is further described in the paper. In the wet method the rubber particles often referred to as crumb rubber or ground tire rubber is reacted by mixing with hot asphalt at a specified temperature for 45-60 minutes to achieve specified binder properties. The resultant mixture of hot asphalt and crumb rubber is the wet process rubberized asphalt binder. Unlike the dry process which can only be used in a dense graded hot mix asphalt, the wet process rubberized asphalt binder can be used as a crack filler, seal coat spray application and in the dense graded hot mix asphalt as well as, gap graded, stone mastic asphalt mix and open graded asphalt hot mix, thus it is much more versatile rubberized asphalt material. The dry and wet process have led to a new type of rubberized asphalt product combining both the dry and wet process attributes, referred to as the dry/wet process. Just like the original dry and wet process materials which started with many crumb rubber patented products so it is with the dry/wet process. The paper describes an example of a dry/wet process material patented product. There is no doubt more dry/wet process materials will arise in the future, as well as* *other products incorporating scrap tire rubber in asphalt, as the goal of attaining a more environmentally sustainable future takes place.*

KEYWORDS: crumb rubber, wet process, dry process, recycling tires, asphalt pavements.

1. Introduction

The asphalt (bitumen) paving industry is concerned with providing an environmentally friendly and green family of products and processes to support a sustainable and circular economy. In the 1970's several patented products incorporating scrap tire rubber in asphalt binder and/or mixes were marketed to enhance and improve various asphalt binder and/or mix properties. The patented scrap rubber products were defined by industry and government as either the wet process or the dry process. This paper focuses on the dry process, however the wet process which is more commonly used is discussed to further demonstrate the substantial differences in these two processes and better delineate why the dry process is seldom used and the wet process is used in many applications worldwide.

Historically in the 1970's environmental concerns was not a major factor in marketing these two processes but over time international studies have shown that climate change is real phenomenon and all industries must develop and use processes and technologies in accordance with climate change concerns. This review paper notes that the wet and dry process began in the early 1970's and by the year 2000 a relatively few limited number tons of mix made with dry process have been constructed, whereas millions of tons of rubberized asphalt mixes made with the wet process have been successfully placed in the world. The rubberized asphalt wet method process is very well documented represented by well over a total of three hundred papers presented at seven international asphalt rubber conferences from the year 2000 to 2018: AR2000 [Portugal 2000], [Brazil 2003], [USA 2006], [China 2009], [Germany 2012], [USA 2015] and [South Africa 2018]. A host of other peer reviewed papers have been presented on the wet method rubberized asphalt in various publications in several journals.

The dry and wet processes historically began as patented products at about the same time in the 1970's coinciding with the growing level of environmental concerns. In the dry process the scrap tire rubber particles act as rubber aggregates or filler of different sizes. The rubber particles are mixed with hot aggregate in the hot plant, then, along with the hot aggregate coated with hot asphalt binder. Following this asphalt coating the resultant hot mix asphalt with the rubber particle aggregates is heated from 15 to 45 seconds and then dumped into a truck to be transported to the laydown machine. The interaction of the rubber particles and the asphalt is a vital and important part of the inherent weakness of the dry process and is further described in more detail in the paper. In the wet process the rubber particles often referred to as crumb rubber is reacted by mixing with hot asphalt at a specified temperature for 45-60 minutes to achieve specified binder properties. The wet process rubberized asphalt carefully considers the rubber particle asphalt time and temperature interaction to achieve a quality rubberized asphalt binder which creates a more elastic rubberized asphalt binder. The resultant specified rubberized asphalt improves durability in crack sealing and seal coating, and reduces cracking and rutting in hot mix asphalt, all of which are desirable performance attributes. The resultant mixture of hot asphalt and crumb rubber is the wet process rubberized asphalt binder. Unlike the dry process which can only be used in a dense graded hot mix asphalt, the wet process rubberized asphalt binder can be used as a crack filler, seal coat spray application and in the dense graded hot mix asphalt as well as, gap graded, stone mastic asphalt mix and open graded asphalt hot mix, thus a more versatile rubberized asphalt material. The paper presents an example of a new type of rubberized asphalt product combining the dry and wet process named the dry/wet process which combines the strengths of the two process. Originally dry and wet process were patented products, so it is with the dry/wet process. Undoubtly more such dry/wet process materials will arise in the future, as well as other products incorporating scrap tire rubber in asphalt, as the goal of a more environmentally sustainable future takes place.

2. Background

The growth in the number of miles of asphalt (bitumen) roadways is tied to the growth in automobiles (cars). For cars to be functionally used all weather structurally sound pavements were needed to keep the cars out of the mud, Figure 1.

1920-1950's Need
For All Weather Pavements

Get the Roadway
Out of the mud

Weather proof and
Water proof the roadway

Develop a pavement surface
That is weather proof and
Water proof

Pavement stand up to wet
Weather, poor soil mud,
And heavy truck traffic

Washington-Richmond road, 1919
NMAH, Archives Center, API Collection

Figure 1: Need for all weather structurally sound pavements

With asphalt becoming the major binder for the paved highways there was recognition that asphalt alone could be modified to improve its durability. Asphalt modified with rubber (AR) was noted as one possible useful modifier. The idea of modifying asphalt (bitumen) with rubber is not new. As early as 1870 Wilkinson [Wilkinson, 1870] patented a material consisting of India Rubber, coal tar and pitch. Very soon after Whiting [Whiting, 1873] patented a material with 1% Balata Gum, the natural polymeric latex secretion from the Balata rubber tree plant, in combination with Trinidad Lake asphalt, oils, rosin and various mineral materials to form a composition suitable for paving applications.

While no roads were documented to use the Whiting technology, there are undocumented reports of road construction in France utilizing natural rubber modified asphalts as early as 1902 [Baumgardner, 2015[. From this 1870 beginning of a concept of modifying asphalt/bitumen, more and more modifiers have been considered including but not limited to polymers of many types, fibers, fillers, various chemicals and many more. Several more patents indicated the usefulness of modifying asphalt with rubber [Pickstone, 1925], [Sadtler, 1930], [Rhodes, 1932], [Grant, 1936], [Taylor, 1954], [Endres 1955, 1964, 1965 and 1966], [Peaker, 1966].

In these patents several benefits of adding rubber to asphalt were noted, improved ductility, coherence, plasticity, and resistance to the action of water [Sadtler, 1930]. Later it was noted improvement in asphalt with rubber included, giving the bitumen elasticity, increase ductility and reduce susceptibility to temperature change [Taylor, 1954]. Later it was observed that vulcanized rubber swells by means of absorbing the lower boiling constituents of the bitumen, thus alleviating serious defects in the bituminous surface, it was also noted that incorporating vulcanized rubber in bitumen would, “provide a new use of some of the 500,000,000 pounds of scrap rubber, such as tires, which are burned each year” [Endres, 1965]. The stage was now set for moving from good intentions, observations and laboratory work to actual full-scale production of rubberized asphalt products in asphalt pavements, starting with asphalt rubber.

Although considerable research and development had occurred from 1870 to 1965 as evidenced by the above patents related to incorporating vulcanized rubber from scrap tires into hot mix asphalt in the United States there had been no practical and consistent means to incorporate vulcanized rubber from scrap tires into hot mix asphalt in the United States. In the late 1960’s research in Phoenix, Arizona lead to various patents being issued in the 1970’s for what is commonly referred in the literature as the McDonald wet process. The Federal Highway Administration defined the Wet Process [Heitzman, 1992] as, “any method that blends crumb rubber modifier with the asphalt cement prior to incorporating the binder in the asphalt paving project.” This applies to sealants, surface treatments, and hot mix asphalt mixtures.

In the 1970’s another patented method of incorporating vulcanized rubber from scrap tires into hot mix was introduced into the USA and referred to as the dry process. The Federal Highway Administration defined the Dry Process [Heitzman, 1992] as, “any method that mixes the crumb modifier with the aggregate before the mixture is charged with asphalt binder.” This process only applies to hot mix asphalt production.

This review focuses on the historical review of the dry process in its many patented and unpatented formulations tested in the United States.

3. Dry Process Origin and Use

The dry process originated in Sweden with a Swedish patent issued in the 1960’s. Two Swedish companies, Skega AB and AB Vaegfoerbaettringar were issued a patent in the late 1960’s and marketed in Sweden under the trade name Rubit. The product claimed to improve skid resistance due to the addition 3 to 4 percent recycled tire rubber from scrap tires to the hot mix asphalt. The rubber particles are 1/16 to ¼ inch (1.6 mm to 6.4 mm / sieve mesh size No. 12 to ¼ inch) and acted like rubber particle filler. The concept put forward was that Rubit added to the hot mix asphalt would act as elastic aggregates and flex under traffic and break the ice thus improving skid resistance [Stuart, 1991].

In the 1970’s the Swedish patent was used to develop two United States patents of the same product [Svensson 1978] and [Lindmark 1985]. This United States patented product was marketed under the trade name PlusRide^{TM}. The Plusride product became the basis for the dry process. In response to the Plusride patented product a generic dry technology was developed by Takallou in 1986. This generic dry process is referred to as either RUMAC or the TAK system [FHWA, 1991] for this product the rubber particles are smaller in size from 0.3 mm to 2.4 mm (sieve mesh size No. 50 to No. 8) [Arkansas 1997]. The Rouse dry process method developed in the same time period as Plusride and RUMAC and used a much finer ground tire rubber crumb (powder) from 0.07 mm or finer to 0.4 mm (sieve mesh size No. 200 or finer to No. 40) [Louisiana 2002] and was tried in a few states.

Many states built test sections of Plusride and/or generic dry process (RUMAC/TAK), and a few states tried the Rouse method. The test sections were constructed from the 1970’s into the 1990’s up to generally when the Plusride patents ended. Test sections of Plusride, RUMAC and Rouse dry process were monitored by several state Department of Transportation agencies for example Oklahoma, New Jersey, California, Arizona, Minnesota, Alaska, Oregon, Colorado, New York and Arkansas. Performance of the dry process was variable with most agencies noting that the dry process by any method did not improve the performance enough compared to the standard control sections to warrant the extra expense. In many test sections surface raveling and early cracking occurred to an unacceptable level warranting early maintenance repairs Appendix A contains some examples of the raveling reported by various states.

4. Dry Process Failure Mechanism Considerations

By the 1990's use of Plusride and the generic dry process as a construction pavement practice had virtually ended. The results of the test sections reported on what happened and cost considerations but why raveling and cracking occurred at an unacceptable level, i.e., the mechanism of failure, was not thoroughly researched or reported upon. Considerable research was conducted on the wet process and the interaction of the rubber particles and the hot asphalt. In 1977 the Arizona Department of Transportation reported on research about how the rubber swells in the presence of the asphalt [Green, 1977]. As shown in Figure 2 the rubber particles begin to swell and interact when placed in contact with hot asphalt binder ultimately becoming a gel like composite consisting of both asphalt and rubber components. As well reported [Way 2012] the reaction between crumb rubber and the light fractions contained in the bitumen during the wet process production usually take from 45 to 60 minutes at about 175° C before placing the asphalt rubber binder in the mix.

In the dry process all the same "ingredients"' are present…crumb rubber, bitumen, light fractions, and temperature…however no specific tests are made to insure at any time that the reaction occurring between the dry crumb rubber and the bitumen during the mixing stage, storage stage, transport at high temperature and during placement some reasonable stable stage 2 gel has been reached. As such it is likely that the performance of dry process mixes will have unexpected performances with some asphalt binder having more or less interaction with the light fractions, and they may interact more or less with the crumb rubber causing the mixes to become "Dry", that is sensitive to moisture damage, reduced fatigue life and lead mostly to raveling. Dry process mix designs did not account for these occurrences. All dry process laboratory mix designs probably seemed acceptable but lacking test information about the asphalt and rubber interaction with time and temperature occasioned unacceptable field performance.

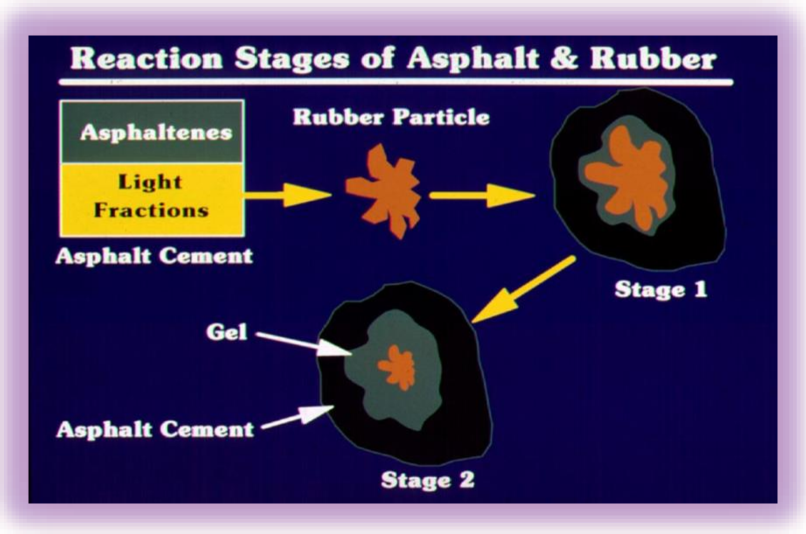

Figure 2: Asphalt and rubber interaction stages of swelling

Actually, it is interesting that Dr. Juan Gallego reported in his thesis [Gallego 1999] that research showed that the performance of pavement layers built with crumb rubber introduced using the dry process were affected by how long the mix stayed in the silo/truck before being compacted. Better performance was found for mixes that stayed in silo/truck longer.

All the above information further reinforces the hypothesis that the rubber particles interact with the oil in the asphalt in the hot mix thus reducing the film thickness and quality of the dry process bond, namely aggregate/asphalt/rubber/asphalt/aggregate matrix, making the mix more susceptible to aging, embrittlement, raveling and cracking. The Plusride and generic dry mix were noted in the literature as being difficult to design the optimum asphalt binder content which may have contributed to some degree to the observed unacceptable field performance.

Notwithstanding the above, the dry process from time to time may still be placed for various reasons. Clearly if very little crumb rubber is placed in the dry process probably it will not impact the mix much but again why placing a little? The possibility now of placing significant amounts of crumb rubber with outstanding benefits on performance is what leads to the environmental benefits that follow from being able to reduce layer thickness.

Successful crumb rubber usage appears to be tied to strict controls on the binder testing (blend of bitumen with crumb rubber or bitumen and reacted and activated rubber). The California, Arizona, Texas, and ASTM specifications clearly state the requirement of specific binder properties after 45 to 60 minutes of blending time when the wet process is used.

5. New Dry/Wet Process Reacted and Activated Rubber

As a result of this review of both the dry and wet process the paper considers a new type of rubberized asphalt product combining both the dry and wet process. The new type of rubberized asphalt is referred as the dry/wet process which combines the strengths of the two processes to create more environmentally friendly and sustainable rubberized asphalt. Just like the original dry and wet process which started with many crumb rubber patented products, so it is with the dry/wet process. This new Dry/Wet process, like its predecessors is a patented product [Sousa 2017]. The Dry/Wet process combines the strengths of both processes. In the Dry/Wet process the crumb rubber particles are reacted and activated with asphalt binder and a filler to produce a dry powder Figure 3 that can be rapidly and efficiently handled and mixed with the hot aggregate and hot asphalt in the same manner as the dry process. Unlike the previous dry process rubber, the reacted and activated rubber immediately interacts with the hot asphalt and becomes the equivalent (if not better) wet process asphalt rubber. No additional mixing or heating equipment is needed, nor is a premixing reaction time of 45-60 minutes thus saving energy and reducing CO2 emissions. The reacted and activated rubber asphalt binder is specified to meet critical properties. German and Portuguese specifications control the ring and ball and penetration before and after RFTOT to ensure that the reacted and activated rubber is sufficiently well processed so that to guarantee that the variation is not above so relatively small limits. Portuguese specifications also control the increase in viscosity over a two-hour period towards the same goal.

REACTED and ACTIVATED RUBBER

(components in optimized proportions and activating environment)

Figure 3: Components – Aspect of Reacted and Activated Rubber

Figure 4 shows Table 1 from a German specification for reacted and activated rubber to be use in 20 and 35% per total binder content [German 2010].

It can be observed that they ensure that the rubber is reacted by imposing limits on how much the softening point can increase and the penetration decrease.

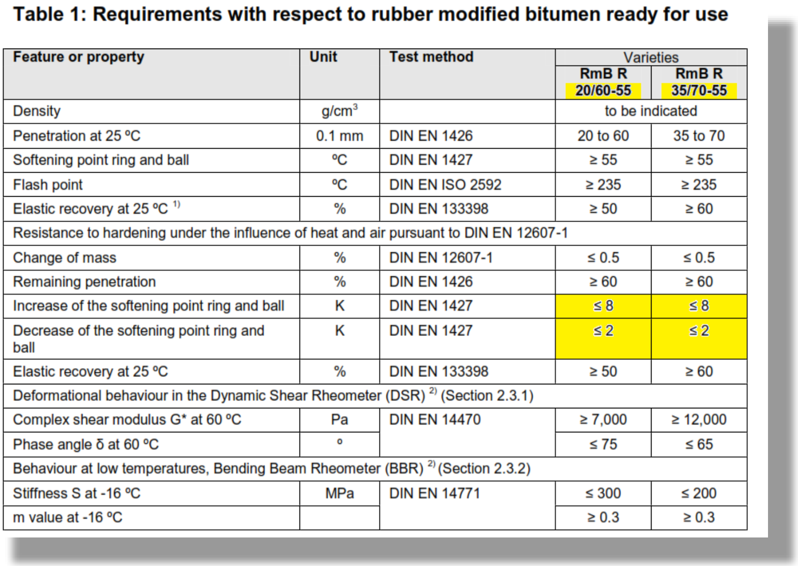

Table 1: Requirements with respect to rubber modified bitumen ready for use

Feature or property	Unit	Test method	Varieties	
			RmB R 20/60-55	RmB R 35/70-55
Density	g/cm³		to be indicated	
Penetration at 25 °C	0.1 mm	DIN EN 1426	20 to 60	35 to 70
Softening point ring and ball	°C	DIN EN 1427	≥ 55	≥ 55
Flash point	°C	DIN EN ISO 2592	≥ 235	≥ 235
Elastic recovery at 25 °C [1]	%	DIN EN 133398	≥ 50	≥ 60
Resistance to hardening under the influence of heat and air pursuant to DIN EN 12607-1				
Change of mass	%	DIN EN 12607-1	≤ 0.5	≤ 0.5
Remaining penetration	%	DIN EN 1426	≥ 60	≥ 60
Increase of the softening point ring and ball	K	DIN EN 1427	≤ 8	≤ 8
Decrease of the softening point ring and ball	K	DIN EN 1427	≤ 2	≤ 2
Elastic recovery at 25 °C	%	DIN EN 133398	≥ 50	≥ 60
Deformational behaviour in the Dynamic Shear Rheometer (DSR) [2] (Section 2.3.1)				
Complex shear modulus G* at 60 °C	Pa	DIN EN 14470	≥ 7,000	≥ 12,000
Phase angle δ at 60 °C	°		≤ 75	≤ 65
Behaviour at low temperatures, Bending Beam Rheometer (BBR) [2] (Section 2.3.2)				
Stiffness S at -16 °C	MPa	DIN EN 14771	≤ 300	≤ 200
m value at -16 °C			≥ 0.3	≥ 0.3

Figure 4: Table from German Specifications Identifying Requirement for Binders for Mixes Made With RAR

It can be observed in the Portuguese [Portugal 2021] and Saudi [Saudi Arabia 2021] Table 3 specifications shown in Figure 5 to ensure that the crumb rubber is properly activated and reacted, 40% of it has to be blended with the bitumen to create a binder that must satisfy specifications including; increase in softening point, decrease in penetration after RTFOT is limited, and increase in viscosity over a two-hour period at 177° C is limited.

In both the wet process, and the reacted and activated rubber product, the incorporating of the crumb rubber in the mix, the binder is properly controlled to ensure the resultant asphalt rubber binder and mix properties are at a much higher level than regular mixes. Figure 6 shows a Table 2-1 from the Caltrans Design guide [California 2003] where the asphalt rubber binder must meet specific properties as a function of the reaction time. No such controls are placed in dry process mix designs.

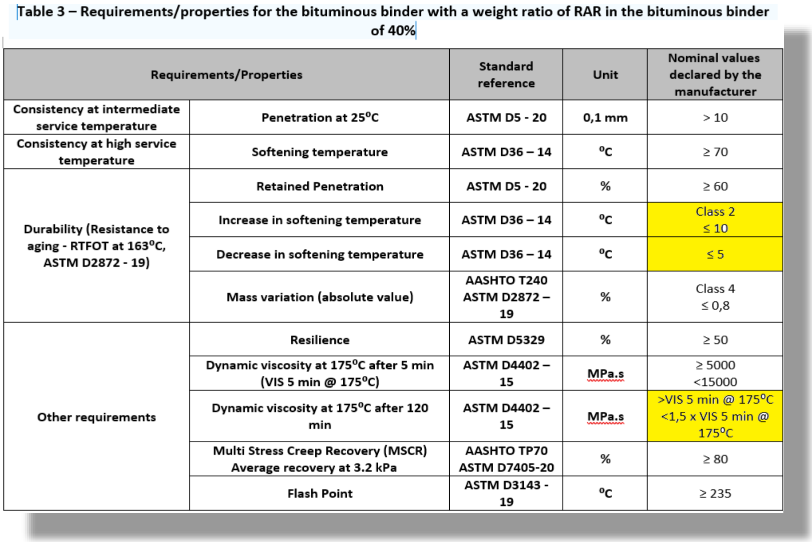

Table 3 – Requirements/properties for the bituminous binder with a weight ratio of RAR in the bituminous binder of 40%

Requirements/Properties		Standard reference	Unit	Nominal values declared by the manufacturer
Consistency at intermediate service temperature	Penetration at 25°C	ASTM D5 - 20	0,1 mm	> 10
Consistency at high service temperature	Softening temperature	ASTM D36 – 14	°C	≥ 70
Durability (Resistance to aging - RTFOT at 163°C, ASTM D2872 - 19)	Retained Penetration	ASTM D5 - 20	%	≥ 60
	Increase in softening temperature	ASTM D36 – 14	°C	Class 2 ≤ 10
	Decrease in softening temperature	ASTM D36 – 14	°C	≤ 5
	Mass variation (absolute value)	AASHTO T240 ASTM D2872 – 19	%	Class 4 ≤ 0,8
Other requirements	Resilience	ASTM D5329	%	≥ 50
	Dynamic viscosity at 175°C after 5 min (VIS 5 min @ 175°C)	ASTM D4402 – 15	MPa.s	≥ 5000 <15000
	Dynamic viscosity at 175°C after 120 min	ASTM D4402 – 15	MPa.s	>VIS 5 min @ 175°C <1,5 x VIS 5 min @ 175°C
	Multi Stress Creep Recovery (MSCR) Average recovery at 3.2 kPa	AASHTO TP70 ASTM D7405-20	%	≥ 80
	Flash Point	ASTM D3143 - 19	°C	≥ 235

Figure 5: Table from Portuguese and Saudi Arabia Specifications Identifying Requirement for Binders for Mixes Made with RAR

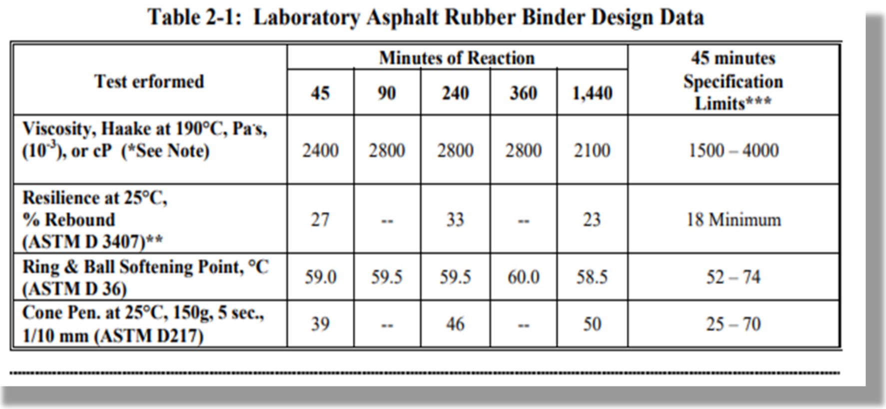

Table 2-1: Laboratory Asphalt Rubber Binder Design Data

Test erformed	Minutes of Reaction					45 minutes Specification Limits***
	45	90	240	360	1,440	
Viscosity, Haake at 190°C, Pa·s, (10^{-3}), or cP (*See Note)	2400	2800	2800	2800	2100	1500 – 4000
Resilience at 25°C, % Rebound (ASTM D 3407)**	27	--	33	--	23	18 Minimum
Ring & Ball Softening Point, °C (ASTM D 36)	59.0	59.5	59.5	60.0	58.5	52 – 74
Cone Pen. at 25°C, 150g, 5 sec., 1/10 mm (ASTM D217)	39	--	46	--	50	25 – 70

Figure 6: Table from Caltrans Specification Identifying Requirement for Binders for Mixes Made with Asphalt Rubber

6. Current Observations about the Dry and Wet Process

By 2018 a Federal Highway Administration sponsored report [Baumgardner, 2020] the authors reviewed the dry process technology starting in the 1970’s into the 2000’s. The report stated that, “...these technologies (Plusride and generic dry process) are no longer marketed for use in the current U.S. GTR-modified asphalt market.” In essence for a variety of reasons the dry process as originally developed and tested in Sweden and the United States had effectively ended. The authors noted their suspicions about why the dry process mixes were prone to ravel, “As previously stated, there is concern that the dry added GTR may lack enough reaction time to provide the desired viscosity increase.” This statement is in keeping with reported performance and research like that of Juan Gallego [Gallego 1999].

The authors of the above report proposed a new 2018 definition of the dry process. “A process where hot-mix asphalt mixture is modified with ground tire rubber (GTR) using GTR as an aggregate/binder modifier which is incorporated into the aggregated prior to mixing with asphalt binder producing a GTR-modified hot-mix asphalt mixture. GTR used in this technology is generally less than 0.6 mm (30 mesh).”

The new definition of Dry Process represents a family of new products which as of yet do not have a design, construction, and performance history, nevertheless, the quest for a quality dry process product using recycled rubber from scrap tires to benefit the pavements and the environment continues to be a worthy goal and undoubtedly other new innovative products representing the advantages of the dry process and the wet process will continue to develop.

7. Conclusions

The asphalt (bitumen) paving industry is concerned with providing an environmentally friendly and green family of products and processes to support a sustainable and circular economy. The use of recycle tire rubber is a win/win strategy for supporting a sustainable and circular economy.

The previous use of the dry process from the 1970’s to the early 2000’s was not a successful paving technology and is not currently marketed.

The wet process from the 1970’s to the present continues to be a viable and very useful paving technology.

The recent development of a dry/wet process method referred to as reacted and activated rubber asphalt is a product that is a useful paving technology. The reacted and activated rubber dry powder successfully takes advantage of the dry process of plant mixing efficiency and the wet process field performance.

There is no doubt more such dry/wet process materials will arise in the future, as well as other products incorporating scrap tire rubber in asphalt, as the goal of a more environmentally sustainable future takes place.

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Appendix A – Examples of Dry Process Raveling

Plusride raveling report Minnesota

State of Minnesota, “Evaluation of “Plus Ride™” (Rubber Modified Plant Mixed Bituminous Surface Mixture), Special Study 387, Construction/Interim Report, March 1986, Prepared By Harvey S. Allen Research Project Engineer, Office of Research and Development, Minnesota Department of Transportation.

“G. Condition Survey

On the T.H. 61 Forest Lake project, raveling of the Plus Ride™ surface was noted. The raveling occurred in the southbound passing lane which was the first lane constructed. In one area, the raveling was to the extent that the thickness of the Plus Ride™ surface had been removed. Figures 11 and 12 show some of the raveling that occurred.

In November 1984, 1,224 linear feet of the passing lane of the Plus Ride test section at Forest Lake was removed and replaced with conventional pavement. This was an area of raveling and debonding. Raveling continued in the passing lane during the winter of 1984/1985 and all but a 100-foot segment of this test section (both lanes) was removed and replaced in the summer of 1985.”

Figure 11 – Raveling of PLUS RIDE Mixture

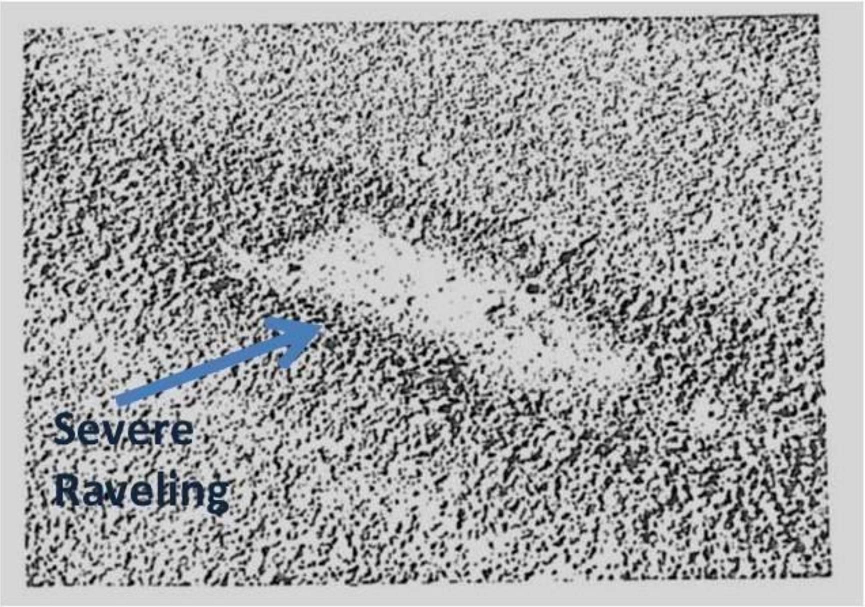
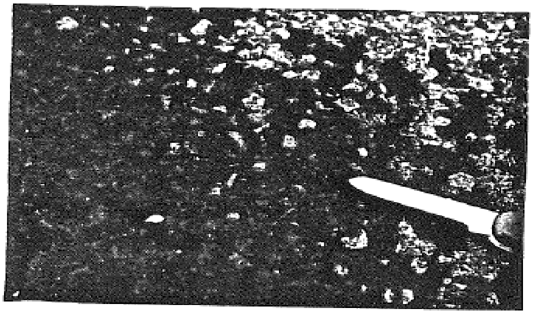


Figure 12 – Raveling of PLUS RIDE Mixture

Plusride raveling report Colorado

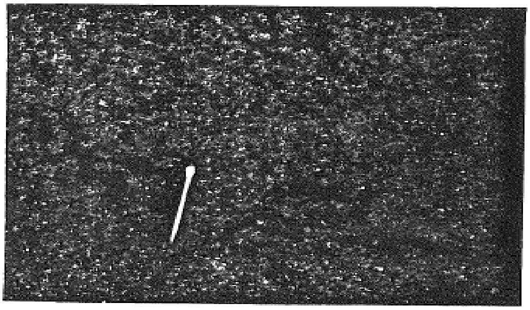
Colorado Department of Highways, “Rubber Modified Asphalt Concrete”, Robert L. LaForce, Colorado Department of Highways, Final Report, Report No. CDOH-SMB-R87-15, December, 1987.

“In each case, there appears to be a cohesive type failure within the Plus Ride mat associated with loading. Following this failure in cohesion, the pavement is broken up and raveled away by traffic.” Photos from report.



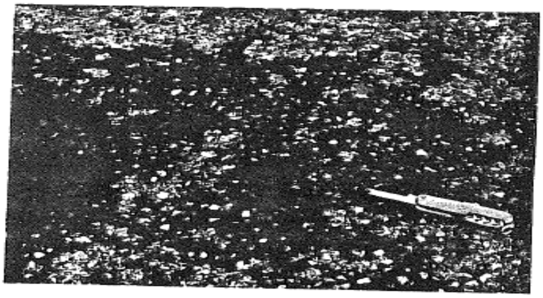
Photograph No. 1
March 2, 1988
West 88th Avenue-
Arvada, Co.

Large rubber granules debonding on the pavement surface.



Photograph No. 2
March 2, 1988
West 88th Avenue-
Arvada, Co.

Hairline cracks with slight debonding to the left of the pencil.

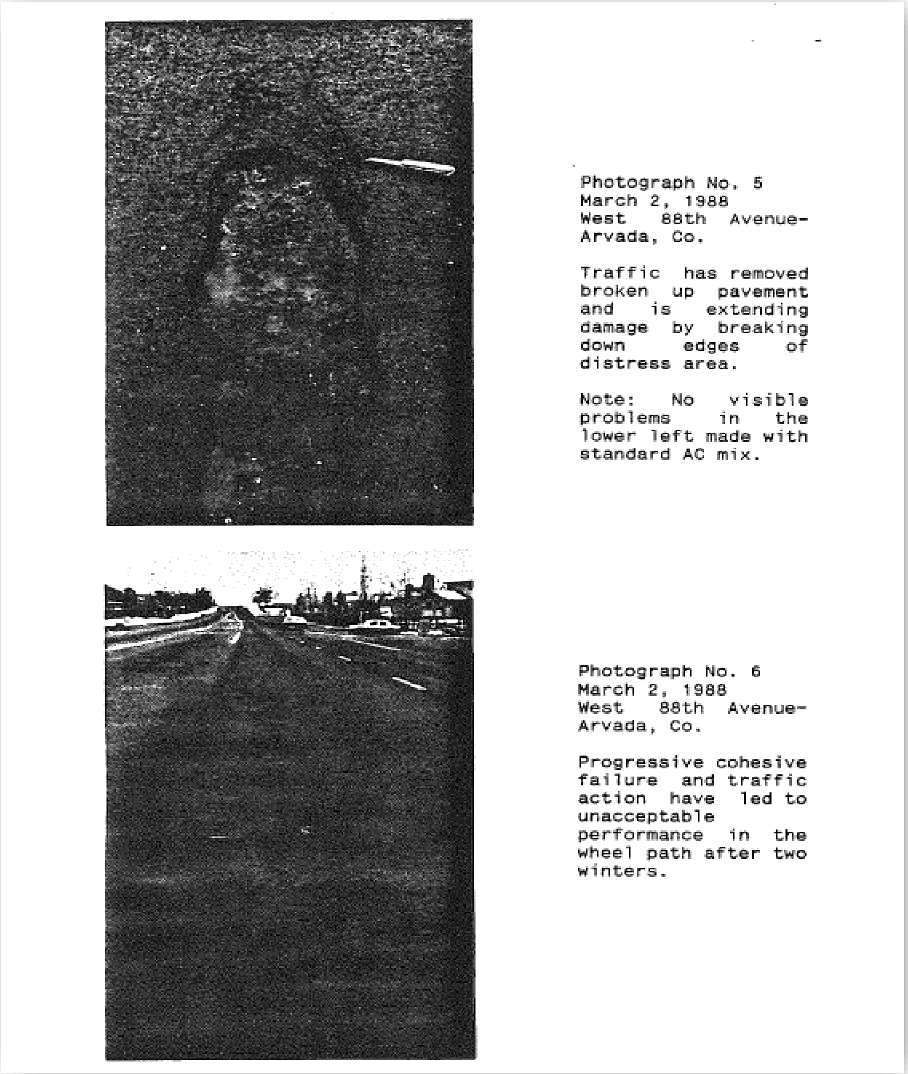


Photograph No.3
March 2, 1988
West 88th Avenue-
Arvada, Co.

Progression of cohesive breakup in pavement.

Photograph No. 4
March 2, 1988
West 88th Avenue-
Arvada, Co.

Further progression in the pavement breaking into chunks and traffic starting to remove larger pieces.



Photograph No. 5
March 2, 1988
West 88th Avenue-
Arvada, Co.

Traffic has removed broken up pavement and is extending damage by breaking down edges of distress area.

Note: No visible problems in the lower left made with standard AC mix.

Photograph No. 6
March 2, 1988
West 88th Avenue-
Arvada, Co.

Progressive cohesive failure and traffic action have led to unacceptable performance in the wheel path after two winters.

Rumac raveling New York

State of New York report, Report FHWA/NY/SR-92/107, “Performance of Two Rubber-Modified Asphalt-Concrete Overlays: A Three Year Progress Report, THOMAS F. VANBRAMER, Special Report 107, Engineering Research and Development Bureau, New York State Department of Transportation, December 1992.

"This report covers an extension of that study addressing the issues of the performance and service life of rubber-modified asphalt concrete (RUMAC) pavements. Performance is recorded semiannually and types and locations of distress are documented. Falling-weight deflectometer tests and laboratory analyses are also conducted. Lab and field testing and performance are reported up to date. Early results indicate that RUMAC pavements are not performing as well as conventional mixes." Photo from report.

Figure 3. Typical raveled areas resulting from shear failure on Route 17.