RUBBER AS AN ADMIXTURE IN BITUMINOUS CONCRETE

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R. L. Braithwaite

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Rubber as an Admixture in Bituminous Concrete

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by

R. L. Braithwaite

Candidate for the Degree of

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TABLE OF CONTENTS

PREFACE

The recent war has caused considerable deterioration of highways in Michigan, due to neglect and lack of materials. Lack of adequate funds prohibits the rebuilding of new reinforced concrete highways, so that the Highway Department is forced to resurface the over-age concrete roads with bituminous materials. Research with rubberized asphalt pavement seems in order.

Hot bituminous plant mix has given good results in the Michigan climate. Deviations from the regular procedure must be made when adding crude rubber, such as lowering the temperature while mixing, to prevent damage of some of the rubber properties. Albeit, synthetic rubber, as devised by Goodyear, permits normal operations.

The writer is deeply indebted to the Goodyear Tire and Rubber Company for their invaluable data and pictures, and to Mr. Finney of the Michigan State Highway Department.

In spite of the general trend in recent magazine articles, the idea of introducing rubber into asphalt for road surfacing is not new. The first patent that could be found by the writer was that of Cassel, in 1844 (British patent #10,327). In 1899, de Caudemberg patented a product (German patent #116,126) which he called Kautschuk-asphalt. This material was to be used to surface roads and any other applicable surface, such as terraces, sidewalks, tennis courts, etc. To obtain this product he permeated a solution of rubber in benzene, petrol-ether, or turpentine into powdered asphalt. The resultant powder could be collected into a mass, lending an elastic surface when rolled at a low temperature.

The technique of combining rubber and asphalt has made important advances in certain foreign countries between 1930 and 1946, namely Malaya, Holland, and England.

The Rubber-Foundation of Amsterdam, Holland employed natural rubber in asphalt for paving quite extensively before 1936. The rubber used was in the form of a powder produced from natural rubber latex, and employing a process patented by the Dutch. A mixture of hot asphalt and rubber powder was heated and agitated for several hours. The heating took place about 200 degrees F. above the softening point of the asphalt, causing the volatile oils of the asphalt to be absorbed by the rubber; the result was an increased softening point and a reduced penetration. These factors explain why the asphalt is more ductile and less susceptible to temperature changes; and since swollen, elastic rubber particles are present, the material is less brittle.

The rubberized asphalt was then mixed with ground limestone and sand to form a top dressing over a course asphaltic concrete base. The numerous sections of roadway produced in this manner, in 1936, held up very satisfactorily under Hitler's invasion of Holland, and are still in excellent condition.

France, although having done extensive research in this field, has few rubberized asphalt roads. This may be due to the tremendously high cost of rubber before the war which made such roads prohibitive. Moreover, asphalt without such an additive gave satisfactory results.

In normal times, the ratio of the price of asphalt to the price of rubber on the world market varies between 10:1 and 15:1. This ratio determines to what extent rubberized asphalt pavements will be used.

A satisfactory method has not yet been found whereby scrap or reclaimed rubber can be used to produce an advantageous surface.

As one may expect, the largest user and producer of asphalt is the United States. Its average output during the last decade has been eight million tons per year. During the next five years, this output may rise to ten or twelve million tons per year.

Before 1940, natural and synthetic rubber was produced at a rate up to about 800,000 tons per year. So far, any extensive use of rubber for paving in the United States has not occurred. As yet, it has been employed on city streets only. The general trend has been to employ rubber for this purpose when rubber prices were low. However, Goodyear at the present time is encouraging the use of synthetic rubber.

The main problem in France, and everywhere (though in the United States rubberized asphalt pavements about one inch thick can be produced for less than ten cents per square yard) is the high cost of the rubberized roads; and the only solution is for extensive research, in the prospect that a more economical method can be reached. Until then, only those countries which have a large supply of rubber can hope to realize a widespread use of this improved type of road, which has numerous advantages over those asphalt roads without rubber. It is difficult to say whether rubberized asphalt roads and all their indisputable advantages overbalances the higher cost of producing them, in these countries. It must be kept in mind, throughout this thesis, that numerous other materials and methods can be used to incorporate the rubber admixtures. The writer will attempt to group the different factors involved under rubberized asphalt pavements, as outlined in the table of contents.

I. Expedient Characteristics of a Hydro-Carbon Road Binder.

Any type of completed pavement surface is composed primarily of a rock aggregate which is held in place by a binder. The binder may be water, as used in concrete; it may be a fine limestone silicate-sand, such as that used in Macadam; or it might be a hydro-carbon binder, for example, such as that used in asphalt and tar-bound surfaces. Following are some of the qualities which a good binder should possess.

(1) The material should be able to hold the aggregate solidly in place under normal conditions of temperature and climate; in other words, it must be able to hold up under conditions to which it is to be subjected. In order to do this it must possess the following qualities: (a) so that water action on the road surface will not separate the aggregate from the binder, there must be excellent adhesion between the rough rock aggregate and the binder; (b) an internal adhesion sufficient to overcome the shock of normal traffic so as to prevent cracking, and also a sufficient rigidity of the road surface as a whole, so that the binder maintains the aggregate in original position; (c) it must demonstrate an appreciable plasticity so that it may absorb the shocks of normal traffic.

The aggregate pieces will become separated from each other and the road surface will rapidly deteriorate if the conditions are not met. Moreover, these qualities must be realized under extreme temperature changes, which are common in the temperate zone. If the binder becomes too soft in the summer months, it looses its cohesion, and as a result the road becomes plastic, and soon the surface becomes wavy; interfering with traffic and proper road maintenance. However, if the binder becomes brittle in cold temperatures, cracks will soon appear. These cracks will introduce water, and successfully spoil off particles, and as a result, a rapidly disintegrating surface will appear. The shock of passing traffic will further break up the hard and brittle road surface.

The cohesion, adhesion, and the plasticity must remain fairly constant. Therefore, a binder possessing excellent aging qualities should be used. Sufficient impermeability is necessary to prevent water from entering the road, and as mentioned before, the binder must resist extreme temperature changes.

(2) It seems evident that the road should not be slippery. The technique employed prior to 1939 was the introduction of a motley of small stones. With this arrangement, the binder must not ooze between the small stones and eventually cover them. Frequently, through pressure, and capillary action, the oily part of the binder rises to the surface and creates a hazardous surface. The binder should contain as little as possible of these oily integrants.

(3) Lastly, the binder used should be able to be easily introduced into the aggregate, and should not require complicated machinery, nor unbearable temperatures. Asphalt, even without admixtures meets these requirements, and is, by-in-large, the most satisfactory hydrocarbon binder available in the road construction field. A complaint common to asphalt is that it is too susceptable to temperature variations, and

that the capillary sweating of the oily parts of the binder is a drawback; however, these defects are present, and much more pronounced in coal tar pitch.

Fillers have been incorporated, mainly powdered carbon and colloidal, to overcome these defects. Blown asphalt also is inclined to overcome these undesirable tendencies. However, as we shall soon see, the best solution to all of these problems is accomplished by the addition of rubber to the asphalt.

II. The Action of Rubber on Asphalt.

The addition of powdered rubber to asphalt has been reported to cause the following improvements in the asphalt:

1- improved impact resistance
2- increased elasticity
3- increased softening point
4- increased viscosity
5- reduced penetration
6- reduced penetration

Perhaps the best theoretical explanation of the property changes caused by the addition of rubber to asphalt is this: photomicrographs show that the observed property changes do not occur because of the formation of homogeneous solutions of asphalt in rubber, or vice versa, since particles of rubber can be seen distinctly in the mixture. The improvements are caused by the presence of rubber particles, swollen up five times their original volume, by the selective absorption of the oily constituents of the asphalt, thus forming an elastic gel.

Asphalt may be considered to be a colloidal system containing asphaltenes or particles that are dispered in high molecular weight aromatic hydrocarbon resins, and low molecular weight oils. When powdered rubber is added to this system it appears as thought the low molecular weight oils are slowly absorbed by the rubber, a process whcih may be hastened by heating. In this manner, the rubber particles are converted into gel structures which are dispered with the asphaltenes in the resin constituents of the asphalt. These resins are hardened by the abstraction of the low molecular weight oils which are thought normally to be plasticizers for the resins.

It must be remembered that to the naked eye, this mixture appears to be perfectly homogeneous.

If the afore-mentioned premises are what actually happens, reasonable explantion for the improvements necessarily follow. Removal of the plasticizing oils from the resins which are the continuous phase of the system, would tend to increase the vicosity and softening point and decrease the flow and penetration. The presence of highly swollen, elastic particles of rubber gel should impart rubbery characteristics to the mixture, hence improving elasticity and resistance to impact. Similar phenomena have been observed in combinations of rubber and several of the synthetic resins and polymers that are currently available.

Several types of fillers are used in conjunction with the rubberized asphalt pavement. Some of them are: sand, limestone, asbestos powder, sawdust, iron slag, cement, lime, plaster of Paris, clay, magnesia, carbon black, zinc oxide, and pulverized coal. The kind of rubber are equally varied: latex rubber, rubber in crumb form, "Nitrite" rubber, chlorinated rubber, waste rubber, balata pitch, gutta percha, and synthetic rubber.

Let us now investigate the influence that the addition of rubber has on the finished road surface.

1. Adhesion

There are many diversified opinions in regard to the question of adhesion. Many believe that the rubber has no influence whatever, while some maintain that it actually improves this quality, while still others point out that it decreases the adhesion already possessed by the binder. Maurice Poncel in his article states that he believes that the adhesion is reduced considerably by the addition of rubber. This is the explanation he advances.

> The asphaltenes and the resins of the bitumen, in order to develop their full adhesive power, require a full degree of elasticity which they develop only in the presence of the proper amounts of the oily constituents. It is possible, on account of the absorption of part of the oils by the rubber, that the resins and asphaltenes are robbed of some of their plasticity and, as a result, have also lost some of their adhesive qualities.

For instance, bituminous rubber emulsion, on a road surface, "breaks" rapidly and the aggregate separates. Individual grains of sand can be seen cutting through the surface layer of the binder.

However, several experimenters maintain that adhesion is actually gained by the addition of rubber, among them are Fol and Plaizer, and Van Haagen.

In order to utilize all of the numerous advantages of rubberized asphalt, it is necessary to prevent the loss in adhesion, if any. This can be done by the intelligent selection of production procedures; these, later in this paper, will be discussed.

2. Internal Cohesion

With the addition of rubber, the internal cohesion is definitely improved. This is because the absorption of the oils by the rubber increases the viscosity and as a result of the paring of the intemmicellar liquid, a bond evolves between the micells (a unit of structure built up from complex molecules in colloids of the resins; These factors allow us to produce a road surface in which the rock particles are geld firmly in place. Furthermore, if the problem of adhesion is also encountered, the separation of the binder from the aggregate surfaces will be hindered by this added internal cohesion.

3. Plasticity

Certain indications suggest that the addition of rubber does not appreciably alter the plasticity of the asphalt (although several authors maintain that the additive actually increase the plasticity). Although one might expect a lower plasticity because of the loss of the oily constituents, this is compensated, at least partially, by the fact that the rubber-oil gel created is of a plastic nature. Howbeit, this rubber additive lends to the asphalt a property which is not present in the pure asphalt. This quality is road surfaces which will have a greater resistance to deformation, will much more effectively absorb the shocks and vibrations which will eventually lead to noisless travel.

4. Susceptibility to Temperature Variations

One of the most important effects of the addition of rubber on the binder is decreased susceptibiltiy of temperature changes. If unmodified asphalt is subjected to high temperature, the low molecular weight oils distill out; changing the entire composition of the asphalt. The rubber, is present, absorbs these oils and forms the rubber gel structure and the escaping of the oils by volatilization is greatly decreased. Liquid plasticizers are highly susceptible to temperature variations, being very active at high temperature, and inactive at low temperature. Because of this, unmodified asphalt, containing low molecular weight plasticizing oils, are very sticky at high temperatures, and brittle at low temperature. These oils are bound in the rubber gel structure, and the oily constituents which are so susceptible to temperature changes are virtually eliminated.

This quality overcomes the possibility of waves appearing in the road surface; and instead of cracks forming in cold weather, the binder is actually supple.

5. Aging Qualities

Because of the lack of a sufficient number of tests, no safe conclusion can be drawn concerning the aging qualities of a rubberized asphalt binder; however, it seems evident, because of the absorption of the oily constituents, the rubber must improve the aging qualities of the asphalt, assuming that the rubber gel ages normally.

6. Impermeability

Since the asphalt itself is sufficiently impermeable under normal conditions, one cannot say that the impermeability is actually improved with the addition of rubber. However, as already stated the formation of cracks by cold weather is hindered; therefore the impermeability, is, in a sense,. increased. Here again, rubber has a favorable effect.

7. Sweating and Slipperyness

A rubber-asphalt mixture has a definite advantage with respect to sweating and slipperyness. Because of the fixation of the oily constituents of the binder, there is no tendency for capillary sweating; hence, no slippery oils to cover the rocky surfaces of the road.

8. <u>Ease of Working the Material</u>

Of course, the process selected to lay the road slab controls the ease in which it is worked.

The small addition of rubber ((5%-10%) creates indisputable improvements in the rubberized asphalt. These improvements are really induced by the expansion of the rubber material by the oils of the asphalt. These improvements should compensate for the increased price of this binder, although these qualities must be utilized to the fullest extent.

Using pure rubber, a 5% rubber content will cost at least twice as much as an ordinary mix, although using synthetic rubber powder, the cost is considerably reduced.

This utilization can be accomplished only by perfecting a homogeneous mixture, and by compensating for the lack of adhesion induced by the rubber admixture. Finally, as we know, crude rubber can be improved by vulcanization; it necessarily follows that the maximum qualities can only be obtained by effecting a kind of vulcanization of the road surface on the basis of a rubber asphalt binder. We will now see by which processes we are able to solve these various problems.

III <u>Processes for the Incorporation of Rubber into Asphalt for Road Surface Construction</u>

The numerous publications and research concerning these processes consist essentially of the following categories.

These procedures have been used mainly in the Far East, England, and Holland, and more recently, in the United States.

1. <u>The Use of Vulcanized Scrap Rubber</u>

The use of vulcanized scrap rubber as the additive may at first seem attractive because of the reduced cost of the material.

The Dussek process (English patent #465,598; French patent #811,750) will be cited as the first example:

Dussek uses such scraps as bags (hot water bottles), rubber, and balloons, and such other scrap rubber that are very elastic. He heats for one minute, in an ordinary asphalt mixer, at a temperature of 150 degrees C., a mixture of:

70-86% (volume) of rock aggregate
9-15% (volume) of asphalt
5-15% (volume) of vulcanized scrap rubber.

The granite aggregate is from 5 mm. to 23.5 mm. in diameter, using Trinidad asphalt or crude oil residue 40 or 50, as the binder. The vulcanized rubber scraps are cut or milled. The patent specifications gives the following limits of the mixture, expressed in percent of the total volume:

	From	To
Aggregate	75	80
Bitumen	12.5	10
Vulcanized rubber	12.5	10
	100	100

The mixture is spread and rolled while hot. The road surface is finished by an application of asphalt emulsion or by spreading an additional layer of hot asphalt with a pulverized rubber additive. Of course, crushed fine rock can be rolled into the surface to give a non-slippery road surface. This process is advantageous in that it is so simple, it varies very little from mixing pure bituminous concrete. However, an important drawback is that it is not a homogeneous mixture; in fact one can see with the naked eye small particles of rubber dispersed in the asphalt. Dussek, himself, states that small particles of rubber was extracted, whether the road mix is prepared at 150 degrees C. for one minute; or at atmospheric temperatures by means of an emulsion. Of course the vulcanized rubber scrap cannot absorb the oily constituents of the asphalt at ordinary temperatures after the road is laid; and without the swelling of the rubber particles, the only purpose accomplished by this rubber is its acting as an elastic aggregate covered with asphalt. Hence none of the desire qualities of a homogeneous mixture of rubber and asphalt, previously mentioned, can be realized. Furthermore, one can expect a hasty disintegration of the road surface with such difference of hardnesses of the two aggregates, rock and rubber. Because of the lack of swelling of this scrap rubber, the finished binder requires 5 or 10 times as much rubber as would have been utilized, using crude rubber, the material is unsatisfactory because of the higher cost of the excess material needed. A satisfactory binder cannot be obtained by simply heating vulcanized scrap rubber with pure asphalt, under the conventional procedures used by our modern road builders.

A more satisforty method is that advocated by Broome, December, 1937. Experiments concerning this method were made by the Trinidad Lake Asphalt Company, the British Road Tar

Association and the London Advisory Committee, and by the Rubber Growers Association.

According to this method, the vulcanized rubber scrap could have been dissolved in kerosene (concentrate 30%) or milled. A road mix is then prepared by mixing in the asphalt mixer for several minutes. The proportion is as follows: 5.12 parts of asphalt, heated to 80 degrees C; 93 parts of dry aggregate, heated to 120 degrees C; and 1.88 parts of the solution of vulcanized rubber in kerosene. The mixture is applied at a temperature of 50 degrees C and rolled immediately. The process is advantageous in that a cheap vulcanized rubber is added, while the mixing procedure varies little from mixing ordinary asphalt. One might add, unless the scrap rubber is kneaded with kerosene for 24 hours at a temperature above 140 degrees C, the mixture will be dissimilar. However, the price may be considerable, and unless one is careful the kerosene may catch fire; albeit, a greater amount of rubber must be used without the kerosene.

In reviewing these considerations, one may conclude that this method for producing rubberized asphalt pavements, is inadequate.

2. Incorporation of Crude Rubber in Hot Asphalt

Whether using crude rubber sheets or crude crepe rubber, it is impossible to obtain a mixture, even if worked at high temperatures and mixing at lenth.

Thielmann (English patent #302,147) advocates melting the crepe rubber at 240 degrees C. before introducing it in the asphalt. However, crude rubber will not regain its original qualities if cooled from tht high temperature. Strength and elasticity are the most important losses. Very finely divided particles of rubber latex may be used advantageously. Davey states that a 40% concentration of ammoniated latex can be perfectly dispersed in asphalt. However, as everyone knows, even a slight amount of water in hot asphalt will cause serious foaming. This probably would be overcome by adding a cupful to a tank car of D.C.N. 200 Silicone-fluid viscosity 1000-Centistolkes @ 25 degrees C., produced by the Dow Chemical Company. Without this, however, the mix may boil over, wasting a considerable amount of the asphalt. Moreover, if intended to coat a dry aggregate, the hydro-carbon binder mixed with even a small amount of water, will seriously effect the adhesion.Mannheimer (Eng. patent #464,562) recommends that the latex asphalt mixer be heated in a current of hot air until all of the water has evaporated. Broom holds that foaming will be held to a minimum if the latex and the other ingredients are mixed all at once. However, the best method is to introduce the rubber in a granulated form.

The Siam process is sometimes used. This is the process in which a granulated crude crepe rubber is disintegrated. The nitrite process is effected by heating granulated rubber in asphalt at 170 degrees C. for twenty hours. These processes, designed to obtain a homogeneous mix, were collected by the London Advisory Committee.

Test roads in Holland were constructed with crude rubber and asphalt. The granulated rubber and asphalt were mixed and subjected to heat for about one hour. The rubber particles were 0.15 mm. or less, obtained by pulverizing latex (Pulvatex). With particles larger than 0.15 mm., the heating period must be increased. The Rubber Foundation of Amsterdam, report number 3 and 7, "Rubber Roads" - (at the International Highway Congress), can be used as reference.

The amount of rubber to be introduced is specified as 5%. This rubber is in the form of Pulvatex Stock or two other marketed rubber powders manufactured for this purpose. One of these rubber powders is called Caoutchoute Filler. It is produced by crushing rubber with Enci Filler until an 8% rubber powder is obtained. The second rubber powder is designated as F.F. Powder. This powder is made up of 35% rubber and 65% of either calcium hydroxide or kaolin.

The several test road surfaces laid by the foundation have the following features in common, the percentage of rubber added is about 5%, except R.F. powder, which is not designated; the rubber powder is introduced into the asphalt as outlined above; and lastly, this surface is laid at a temperature of 130 degrees C.

Here are some of the advantages obtained by incorporating crude rubber powder. The binder will consist of a homogeneous mixture of rubber and asphalt, provided it is thoroughly mixed at a sufficiently high temperature (170 degrees C.). Hence, the mixture will consist of all the essential qualities of a good hydrocarbon binder. Furthermore, it will accomplish the best possible adhesion to the rock aggregate precautions. Again by following this procedure, a simple road mix can be obtained which sets rapidly and is of great solidity.

Of course, this type of binder also has its disadvantageous. The rubber becomes depolymerised, rendering it less effective when introduced into the asphalt. The asphalt is also effected adversely. Variations in the softening point and penetration are caused by evaporating the more volatile constituents; thereby entirely changing the character of the binder. Hence it becomes necessary to avoid overheating the binder. However, this necessitates longer heating periods which is more expensive. Because of the very high softening point of the mix, the mixture is very difficult to lay. Hence the mixing with the aggregate has to be at a temperature of about 160 degrees C., while the subgrade is not above 110 degrees C. The mixing, therefore, must be accomplished in movable mixing kettles; a difficult operation, because of the extreme temperatures and careful observations that must be made. The rolling of the surface laid also requires careful attention.

Taking it for all in all, construction of good surfaces are possible if the necessary precautions are taken; but because of the complicated methods and the cost involved, other processes are preferred.

Number		1	2	3	4	5	6	7
Aggregate	Fine Aggregate				55,3			
	Gravel						55	
	Sand	86	86				14,75	
	Dune Sand			15			22,25	
	Ward Quartz Sand				28,5			
	River Sand					86		100
	Pulverized Balsalte			85				
Filler	Enci Filler	5,7		14	6	6	14	8
Rubber	Caoutchoute Filler	9						
	Stock Powder		0,65					
	Pulvatex		0,3					
	R.F. Powder				1,5	2	1,2	25
Asphalt	Asphalt; 40/50 penetration	13,3						
	Schells Pra		12,35	6				
	Bitume; 50/60				10			
	Bitume Tendre					12		
	Mexphalt 55						7,75	2

3. Fluxing of Hot Asphalt in a Solution of Rubber in Light Oil

Bromme suggests that the granulated rubber be first dissolved in kerosene. By fluxing this solution of rubber and kerosene into asphalt at a medium high temperature, the rubberized asphalt binder is obtained. The rubber content is about 4% of the asphalt. It is readily seen that the resulting material is, in reality, a rubberized cut-back used the same as an ordinary cut-back. To illustrate the adaptability of this binder, assume we use a quarter inch igneous aggregate with this rubber asphalt cut-back. After mixing the 6 parts binder and 94 parts dry aggregate at 120 degrees C. for about three minutes, the material should be laid about a half inch thick at 40 degrees C. Then roll with three rollers weighing three tons, following with a seven ton tandem roller. Traffic can pass in a few days, but the surface does not reach its final consistency until it has aged sufficiently, which depends upon the rate of evaporation of the kerosene. Following, are some of the tests and conclusions drawn by Broome.

Test results (see table I)

1. Suitable rubber crumb may be used, in which case it is not necessary for it to be dissolved in the asphalt binder.

2. Better results are obtained if the light flux oil, such as kerosene, is omitted.

3. If kerosene is omitted, the rubber may introduced in a low temperature paving mixture, by mixing in one stage.

4. Rubber can be conveniently added in latex form, with

other ingredients.

5. Much smaller quantities of rubber latex is needed.

6. Binders with rubber are improved, and has less flow.

7. Using fluxed Trinidad Asphalt, less temperature is needed.

Rubber and Bitumen

Tests carried out by adding rubber to different types of bitumen has provided some valuable results. Five typical bitumens, having a penetration of 200 degrees at 25 degrees C.

1. A "straight-run" asphaltic bitumen (see table III).

2. A "straight-run" asphaltic bitumen in conjunction with Lake Asphalt.

3. An oily bitumen.

4. A "semi-blown" bitumen.

5. An oil-fluxed Lake Asphalt.

The results of these tests and several others show that;

1. The softening point is almost always raised by the addition of rubber; the bitumen with the greatest increase in softening point was (4); while bitumen (3) was least affected.

2. In general, as the rubber content is increased, the penetration is decreased. The opposite occurs when rubber is added in any amount to bitumen (3).

3. The addition of rubber does not materially reduce the ductibility, except with (4) and (5).

4. Extreme viscosity is encountered.

5. Plasticity varies as the viscosity.

6. The blown bitumen mixtures show the highest degree of elasticity.

Type (4) then appears best, with good results with regard to softening point, elasticity, plasticity, and viscosity.

Ordinarily, a blown asphalt is usually brittle at low temperature and has low ductility, but these characteristics completely disappear by adding rubber.

Methods similar to this are the Duryoide process, a mineral oil being the fluxing oil; and the Krishna process, using vicin oil, this method uses large amounts of silver. In other words, a non-volatile oil is used, with the intention of keeping the oil in the binder permanently. The resulting material could hardly be classified as a cut-back.

Because of the simplicity and practicability the Broome method seems the best; hence it will be used as a typical example.

High temperatures or extended periods of mixing are unnecessary because granulated rubber is easily dissolved in kerosene. Also, the rubber solution cuts the asphalt readily, rendering medium high temperatures sufficient. With such temperatures, important properties of the asphalt or rubber will not be diminished. The binder obtained is perfectly homogeneous, and the batches are uniform. Once the kerosene has evaporated, the hydro-carbon binder possesses all of the desirable qualities listed hitherto. The reduced adhesion of the fluxed binder (which is more greatly reduced than that of a pure binder) can be corrected by first covering the aggregate with a pure asphalt binder. The diminished adhesion can also be corrected by using one of the "adhesisphores" as outlined by Vellinger, or by using creosote oil, or any other medium heavy tar oil, as the fluxing oil. Since the mixing takes place around 90 degrees C. and the laying, around 40 degrees C., the construction of the pavement is both simple and economical. One can even lay the mix cold if enough flux is added. Because of this, the material can be stored and transported long distances.

However, the volatile flux is inflammable and high priced; moreover, it is only added to facilitate the working of the mix; the considerable quantity of expensive oil evaporates once the mix is laid, adding much cost. The coating of the aggregate also is quite costly. Since this oil is intended to evaporate, the slab must contain pores, making it impossible to construct a firm bituminous surface. Moreover, the required cohesion is not realized until after a considerable amount of the flux has evaporated, making the passing of traffic impossible for several days. When this has been accomplished, a light sealing coat should be applied: or better yet, a thin layer of asphalt covered sand. A rubberized asphalt binder should be employed in both instances, to insure a surface which will not develop sweating. It would seem advisable to finish the thin top layer by rolling in sharp, one quarter inch gravel to further increase the friction.

Practical applications in France has led that country to favor this method, because of the case with which the mix can be laid, also excellant results were obtained, outside of the fact that the surface did not possess the firmness ordinarily had by a ordinary bituminous-macadam road. Because of the great strides in France, using "bitumacadam" (rubber-containing bituminous-macadam), it seems that the United States, already employing a widespread use of cut-backs, could use this superior mix to their advantage. However, greater speeds, and heavier trucks would necessitate certain improvements over this type of surface, it would seem. It has been suggested that the binder should be mixed in factories, of either rubber or oil companies. However, using synthetic rubber powder, this is absolutely unnecessary, as will be pointed out later. Sulphur and vulcanization accelerators are always added; with sulphur being far in excess of that needed to convert the rubber into vulcanized rubber. Sulphur also increases the elasticity and raises the softening point. Rubber and sulphur should be added in equal amounts.

TABLE I

TESTS ON RUBBER ASPHALTIC CEMENTS

		1	2	3	4	5	6	7
Soft. Pt. (R&B)		40°C	42°C	47°C	40.5°C	45°C	47°C	51°C
Penet.	@ 0°C.	16	12	11	22	14	12	9
	15°C.	75	60	58	75	58	59	47
	25°C.	200	150	136	203	170	142	116
	30°C.	***	246	205	345	235	250	130
	35°C.	***	300+	292	***	***	***	240
Duct.	@ 0°C.	60.0	28.0	64.0	53.8	12.5	34.0	16.5
	15°C.	+100.0	100.0	100.0	100.0	100.0	100.0	100.0
	25°C.	+100.0	100.0	100.0	100.0	100.0	100.0	100.0
	30°C.	***	100.0	100.0	93.0	100.0	100.0	100.0
	35°C.	***	***	***	70.0	100.0	100.0	100.0
Visc.*	@ 0°C.	7.8**	16.9**	16.9**	9.0**	15.4**	14.8**	71.8**
	15°C.	31.8**	47.8**	67.6*	23.9*	41.8**	51.7*	99.0*
	25°C.	***	***	***	***	***	***	***
******	150°C.	56	117	172	61	81	225	663
Plast.	@ 0°C.	57.2%	74.9%	77.1%	84.1%	72.5%	65.4%	91.6%
	15°C.	50.5%	59.5%	69.6%	47.1%	50.7%	61.4%	68.8%
Elast.	@ 0°C.	30	62	70	37	67	75	74
	15°C.	10	40	52	15	35	47	56
Susept. (0-15°C.)		1.181	1.317	1.189	1.34	1.33	1.24	1.59
Fluid (25-150°C.)		72	153	230	83	109	300	756
A.V.I. (0- 15°C.)		19.3	21.1	19.3	21.5	21.4	20.0	24.8
Flow Hrs. @25°C.		2.6cms	1.3cms	0.7cms	3.5cms	2.4cms	2.1cms	1.7cms

Column 1: Asphaltic Bitumen
Column 2: Plus 1% Rubber
Column 3: Plus 2% Rubber
Column 4: Fluxed Trinidad
Column 5: Plus 1% Rubber
Column 6: Plus 2% Rubber
Column 7: Plus 3% Rubber

*
* : Poises
****** : Redwood 2
* : x 10^5
** : x 10^7

*** : Too soft

TABLE II

TESTS ON RUBBER ASPHALT MIXTURES

	1	2	3	4	5	6	7
Aggregate	93.00%	93.00%	93.00%	92.93%	92.93%	92.86%	92.79%
Latex	""	""	""	0.60	0.07	0.14	0.21
Rubber Crumb	0.57	0.57	""	""	""	""	""
Bitumen	5.12	6.43	7.00	6.40	7.00	7.00	7.00
Kerosene	1.31	""	""	""	""	""	""
Rubber % on A.C.	12	12		5.62	1.00	2.00	3.00
Total Mix	0.57	0.57	""	0.36	0.04	0.08	0.12
* Hard# @ 25°C.(1)	17	17	16	26	17	17	17
** Hard# @25°C.(2)	11	4	3	8	6	7	8
45°C.(2)	12	10	5	11	9	10	10
45°C.(1)	63	86	60	108	45	50	60
***Ball Inden.							
@ 25°C.1 m.	""	38	18	22.3	61.0	30.5	33.0
5 m	""	42	80	27.9	63.5	34.7	34.3
****Def.@ 25°C.							
kgs.per cm.	7.97	""	""	5.62	7.83	7.45	7.80
Deformation @25°C.	4.51	5.39	6.08	1.78	4.08	4.05	3.41

* 100 kgs per sq. cm. for one minute
** 100 kgs. for one minute on one-inch ball
*** 400 lbs. on one-inch ball
**** Wilson test. See <u>J. Soc. Chem. Ind.</u>, 51, 61 (1932)
"" Out of range of testing equipment.

(Made with 1/8 inch-dust granite coated with asphaltic cement at a temperature of 70 to 75°C.)

Abnormalties are due to sieve analysis methods used. Also the test results depend more on the interlocking of the aggregates than to the variations in the composition of the binder.

TABLE III

THE GENERAL EFFECT OF ADDING 4% RUBBER TO VARIOUS TYPES OF BITUMEN

Bitumen Type	1	2	3	4	5
Softening Pt. (R&B)	Inc. 25°C.	Inc.	Inc. 15°C.	Inc. 35°C.	Inc. 23°C.
Penetration @ 25°C	Dec. " "	Dec.	Inc. 48	Dec. 131	Dec. 137
Ductility @ 25°C.	" "	" "	" "	Dec. 53cms	Dec. 61cms
Viscosity @ 15°C.	Inc.	Inc.	Dec. 4,000p	Inc. 55,000p	Inc. 12,000p
Viscosity @ 150°C.	Inc.	Inc.	Inc. 370secs	Inc. 333secs	Inc.
Plasticity @ 15°C.	Inc.	Inc.	Dec. 15%	Inc. 31%	Dec. 26%
Elasticity @ 15°C.	Inc.	Inc.	Inc. 1%	Inc. 40%	Inc. 50%

TABLE IV

Asphaltic Bitumen 100 Gms. Plus 25,000 Sq. Cms. Filler

	Asph. Bit.	Cement	Gran.	Lime-stone	Slate	Silica
Softening Pt. (R&B)	38°C	42°C	40°C	42°C	42.5 C	38°C
Penetration @15°C	72	66	61	68	67	66
20°C	115	100	98	112	109	110
25°C	204	186	176	198	187	209
30°C	395	307	268	325	304	326
Viscosity @15°C	1,990	2,388	3,383	2,388	2,189	3,383
Plasticity @15°C	31.5%	32.8%	44.4%	36.6%	28.7%	52.5%
Elasticity @15°C	30	30	21	27	22	31

Asphaltic Bitumen 98 Gms. Plus Rubber 2 Gms
Plus 25,000 Sq. Cm. Filler

	Asph. Bit. 2%Rub	Cement	Gran.	Lime-stone	Slate	Silica
Softening Rt. (R&B)	44°C	45°C	46°C	44.5 C	45°C	47.5C
Penetration @ 15°C	61	55	51	58	54	58
20°C	98	84	80	94	90	86
25°C	178	145	142	170	166	147
30°C	250	218	226	242	247	243
Viscosity @ 15°C	2,189	6,368	6,368	4,776	4,975	6,368
Plasticity @ 15°C	13.8%	64.2%	59.0%	59.6%	52.4%	67.6%
Elasticity @ 15°C	40%	44%	42%	44%	43%	47%

IV Mixture of Asphalt and Rubber Emulsion

Since stabilized latex and standard commercial asphalt emulsions are stable under identical conditions, the two materials can simply be mixed at normal temperatures with no flocculation resulting.

The watery rubber latex is concentrated by evaporation after stabilizing with ammonia and other chemicals. The latex contains about 50% rubber. The latex, consisting of viscous particles ranging from 0.5 to 2 microns (2 x 10-5 to 8 x 10-5 inches) in diameter, and the asphalt emulsion, with particles varying between 0.1 to 10 microns (0.4 x 10-5 to 40 x 10-5 inches) in diameter, can be mixed perfectly, resulting in an average particle diameter of about 4 or 5 microns (16 x 10-5 to 20 x 10-5 inches). When the rubber breaks, a homogeneous rubber asphalt binder is obtained, possessing all of the desirable qualities listed previously. However a slightly diminished adhesion persists, because of the perfect homogenity of the mixture; although emulsifying any asphalt diminishes the adhesion. The problem now is, of course, to somehow restore the adhesion of the binder to the aggregate. By using insoluble ultra-accelerators which are not eliminated with the water contained in the emulsion (namely, type "5" R extra de Saint Denis) it is possible to obtain auto-vulcanization, at ordinary temperatures, after the mix is spread on the road, lending added qualities to the binder.

Since the work is done cold, and the flux consists of water instead of costly oils (kerosene), the use of this type of binder is simple and economical.

Probably the best method of obtaining the desired rubber asphalt binder, is that suggested by Meadows in his 1923 English patent number 216602.

Such a product used on widely in the Netherland Indies is called "Colastex". The binder contains 100 parts of 60% asphalt emulsion and 10 parts of latex. This binder is mixed with the aggregate while hot. Numerous other patents prescribing such a process are in existence.

France has done experimental research along this line. After obtaining their rubber-asphalt emulsion, they proceeded as if it were an ordinary asphalt emulsion. Because the emulsion lacked adhesion, their results were inferior.

Mr. Taylor, Engineer of Roads and Bridges in Singapore, corrected this misfortune in his method. It is described in British patent number 406526 and French patent number 811066. Mr. Taylor remedies the situation by suggesting that the aggregate be first covered with a thin layer of ordinary asphalt, then mixing with the rubber asphalt binder. This covering consists of asphalt thinned with a cut-back oil or hot molten asphalt, or even an asphalt emulsion with such a basic aggregate as limestone, blast furnace slag, etc. This treatment is sufficient to give excellant adhesion to basic aggregates. However, the adhesion of pure asphalt to an acid type of aggregate (porphyry, quartzite, etc.) leaves much to be desired. With such an acid aggregate, the thin coating of asphalt adheres more greatly to the rubberized binder than the aggregate, hence the coating is torn off. Taylor suggest that the acid type of aggregate is treated with a basic material, such as portland cement, blast furnace cement, hydrated lime, etc., prior to treating it with pure asphalt; while making the cement mixture as stiff as possible, so as to place a thin layer on the aggregate surface, and not fuse the several aggregate particles. After allowing the cement to set, the aggregate with a thin layer of pure asphalt is allowed to set. For a silicious sand between 0.04 and 0.12 inches in diameter, the following procedure is recommended. After mixing 85 parts sand, 10 parts portland cement, and 5 parts water, the mixture is allowed to dry for 3 hours. Then the material is heated to 150 degrees C., and the aggregate surface is covered with a thin layer of pure hot asphalt, having a penetration of 180 to 200, using 5 parts of the asphalt. Next the sand is mixed with the rubber asphalt binder.

However, this process seems a little involved and expensive compared to the quicker methods advocated in the United States, and as was pointed out, there is some dispute whether rubber actually decreases the adhesion with certain methods of incorporation.

The following aggregates are listed according to their desirability, (the first being the most desirability limestone, dolomite, and blast furnace slag. Silicic aggregates must be avoided if adhesion comparable to that of pure asphalt is expected. However, a small amount of Armeen T will increase the adhesion of the binder.

Roncel, using Taylor's patent specifications, lists the following tow experiments in connection with this type of binder. He used slag sand from zero to 0.12 inches in size. By using this aggregate, excellant adhesion was obtained. He first treated the hot sand, with 5% asphalt; basing that amount of asphalt on the fact that each sand grain retains a thin layer of asphalt, yet retains its pulverized form, and not forming lumps when the material is cold.

The first of these product which were the subject of Poncel's research is listed in the patent as "Bituminized Rubber Mastic." It contains a large amount of rubber. Because sweating is not present, and temperature variations have little affect on this binder, it can be used in relatively large quantities, more than filling the voids in the sand. Hence, the mixture forms a plastic mastic before the emulsion breaks, and the mastic possesses much elasticity after the emulsion breaks. The emulsion contains 60% asphalt, having a penetration of 180 to 200. The asphalt is stabilized so that the emulsion will not break while being mixed with the aggregate. A stabilized latex containing 50% rubber is used, also containing sulphur, zinc oxide, and the required ultra-accelerators so that auto-vulcanization of the road bed takes place in about fifteen days. The following mixture is used:

Blast furnace slag sand covered with 5% asphalt	80%
Asphalt emulsion (60%)	15%
Specially prepared latex (50%). . . .	5%
	100%

The mixing can be done at ordinary temperatures with a concrete mixer. About 21% of the rubber in the binder clings to the asphalt covered aggregate surface. The total amount of binder, including the thin layer of pure asphalt is about 16%. The mastic is so plastic, it is nearly fluid, and can be readily troweled; in other words, it is very workable. Since the rubber content is so high, and since the "rubber is concentrated in the very outer layer of the binder on the aggregate surface," this rubber asphalt binder possesses all the desired qualities of a hydro-carbon binder, to an extreme degree; and furthermore, the adhesion is excellant.

Of course, with such a fine aggregate, "Bituminized Rubber Mastic" can also be used for sidewalk covering, tennis courts, terraces, etc. For a street, a layer about 1 5/8 inches thick is spread on the subgrade and rolled until it has a density of around 1.64 pounds per square foot (8 kg. per sq. meter). Then "Rubber Mastic" is applied with a power-trowel or spreader to fill the pores or openings. This material penetrates and adheres perfectly. Of course, the "Rubber Mastic" should not completely cover the aggregate, since that would tend to produce a slippery surface. To avoid this, about 3% of the mastic per sq. ft. should be applied. The resulting road surface is quite firm. Even after the mastic is broken, the aggregate is held in place by the "Rubber Mastic." In France, it was found that this type of road surface cost about 40% more than a tar-macadam road surface. Excellant results were obtained. Poncel suggests that the amount of latex could be halved, thus reducing the cost 10%.

The second of Taylor's products is called "Rubberized Bituminous Cold Laid Asphalt." The same base material being used in its manufacture, but has less binder, with a binder having less rubber.

Taylor gives the following formula:

	Parts
Blast furnace slag sand 5% bitumen admixed	100
Asphalt emulsion, 60% concentration	5
Rubber latex of 50% concentration	1

resulting in 14% rubber in the emulsified binder and 5.8% rubber in the binder as a whole. A more economical method suggested by Taylor is the following, also giving excellant results:

	Parts
Blast furnace slag sand, 5% bitumen admixed	100
Asphalt emulsion, 60% concentration	3
Rubber latex, 50% concentration	0.5

resulting in 12% rubber in the emulsified binder and 3.5% rubber in the binder as a whole.

These materials can also be mixed in a concrete mixer. But in this latter case, the volume of the voids in the aggregate exceeds the volume of the binder, lending, instead of a mastic appearance, a friable powder. After drying in a stock pile, the material, still retaining its powdery form is easily spread with a power rake, then rolled, forming a solid mass; compacting perfectly at ordinary temperatures with application of pressure. Traffic completes this compaction, and finally a firm and solid road surface take form.

Consequently, Taylor suggests two methods of obtaing rubberized asphalt pavements. However, they must be used wisely, and for such purposes which they were designed. However, these methods are relatigely simple and produce excellant results. Since asphalt emulsions are manufactured on a large scale in the U. S. A., this method appears desireable. Clay suspensions in water are used as stabilizers, and the emulsion contains up to 60% asphalt.

V Use of Finely Pulverized Synthetic Rubber

While visiting Holland, Mr. P. W. Litchfield, Chairman of the Goodyear Tire and Rubber Company Board, was impressed with the durability of the rubberized asphalt pavement in Holland; and as the result of his advice, research was started along the same line, i.e. using a powdered rubber admixture.

Since the highways in the United States are subjected to higher speeds and much heavier roads, our roads are normally superior to those foreign countries. There was considerable doubt therefore, if a rubber admixture could further improve our pavements. For example, the top dressing, or sheet asphalt method of construction has made way for a thoroughly rolled asphaltic concrete with a course aggregate. However, engineers decided to compare Dutch top dressing with our standard roadway, with and without rubber.

Because the natural rubber was expensive and was difficult to obtain, a synthetic rubber powder from the GR-S synthetic rubber was decided to be employed. The powder developed could be produced in large amounts and was found to be more economical than natural rubber.

Several sections of test pavement was laid in September, 1947, in Akron, Ohio, using the Dutch top dressing with natural rubber powder compared to both the asphaltic concrete with a natural rubber powder, and with a synthetic rubber powder. The results of the tests were found so promising that about a mile of rubberized asphalt pavement, containing synthetic rubber, was laid in Akron in 1948. The conditions of this road in the future will guide Goodyear research.

Goodyear, in their research, has used 5%, 7½%, and 10%, based on the weight of asphalt. It will be noted that a percentage is used midway between the two used in foreign countries, namely, 5% and 10%. The asphalt was heated to 300 degrees F, the rubber being sifted slowly by agitation, and heating and mixing was continued for about two hours. As will be pointed out in more detail, the rubber becomes dispersed in the asphalt and swells. The resulting binder was then mixed with the aggregate, consisting of sand and crushed rock, and rolled into place.

The fine synthetic rubber powder, in order to be effective, must pass a 40 mesh seive, and a large amount, passing a 100 sieve.

The Goodyear Research Laboratory found that synthetic rubber powder was more desireable for experimentation than natural rubber powder. Synthetic rubber powder could more easily be reduced to a fine particle size, could more easily be incorporated into the asphalt, and the resultant mixture had a lower initial viscosity. But as already mentioned, the most important advantage was the availability in this country, and lower cost of producing it. Hence, the work of Goodyear has been confined to synthetic rubber powder.

Two methods were devised by which the powder could be produced so as to pass a 40 mesh sieve. Several thousand pounds of this rubber was used in the Akron paving tests.

Because of very suceessful tests of small sections of rubberized pavement laid in 1947, the two mixes, containing 5% and 7½% synthetic rubber, based on the combined weight of the rubber and asphalt, were laid in 1943 on Exchange Street in Akron; a major east-west street carrying a heavy volume of both passenger and truck traffic.

For purposes of comparison, one-half of the street was resurfaced with the ordinary asphaltic concrete normally used in Akron, while the opposite half was covered with the same mixture with 5% and 7½% rubber added. On the west end of the street, the rubberized mixture is on the south side of the street, and on the east end of the pavement, it is on the north side. Over 31,000 square yards of the pavement was resurfaced.

The resurfaced section of Exchange Street was originally paved with brick on a concrete base. Following 27 to 31 years of service, the brick pavement became rough, although it was still strong and solid. Such a condition was an ideal situation for a bituminous resurfacing material; a binder, or leveling course,(containing no rubber) the minimum being 1", and the average, 1½", (and more if needed to fill depressions) was first laid to fill in depressions on the brick surface, and to provide a binder for the new resurfacing. According to Ohio specifications, it was called T-35, Type "A".

5% and $7\frac{1}{2}$% synthetic rubber-asphalt mixtures were prepared as follows. The asphalt was heated in a tank to a temperature of about 270 degrees F. and agitated. The powdered synthetic rubber was introduced into the molten and agitated asphalt by pouring the powder through a screen to uniformly distribute it over the asphalt surface. The mixture was agitated for two hours at 275 degrees F. after which the heat and agitation was discontinued, allowing the mixture to cool slowly overnight. The next morning the mixture was reheated to 275 degrees F. and mixed with sand and limestone in a "double pug mill" according to the following formula:

sand	42.5%
limestone	51.0%
rubber/asphalt	6.5%

The mixing with the aggregate, the transportation of the mix, and the laying of the rubber-asphaltic concrete is the same as for the standard mix.

The mix containing powdered synthetic rubber was similar to a surfacing asphalt mix known as Ohio T-35, Type "C". In the following table, screen size specifications of this road surfacing aggregate are compared to the screen anlysis of the aggregate used in conjunction with the rubber admixture.

Screen Size	Specification	Regular Mix	Rubber Mix
Pass ½ screen	0-7	6.1	2.9
Pass 3/8 screen	24-45	33.0	34.3
Pass #4 sieve	0-15	8.4	10.8

(continued)

Screen Size	Specification	Regular Mix	Rubber Mix
Pass #6 sieve	20-45	36.2	40.1
Pass #50 sieve	3-15	6.5	4.4
Pass #200 sieve	0-5	3.2	1.7
Retained #6 sieve	40-55	47.5	48.0

Standard hot-mix equipment was used for laying the rubber-asphalt aggregate. A Barber Green paver was used for spreading the aggregate and Buffalo-Springfield gasoline rollers were used for smoothing the surface (see photos). In the laying of the mix it was found necessary to change the angle of the Barber Green paver so that an ironing action was simulated rather than the usual stamping action; but otherwise, the rubberized asphalt pavement was laid in the same manner as a standard asphalt mix. Observors reported that the rubberized topcoat did not cut as badly when hot and being rolled as the standard mix.

The following laboratory tests may be of interest, comparing the asphalt used with those compositions of rubber and asphalt containg 5% and 7½% rubber.

Property	Asphalt	5%Rubber in Asphalt	7½% Rubber in Asphalt
Foam when heated to 177° C.	none	none	none
Penetration at 25° C.	75	63	57
Softening Points, deg. C.	49 to 53	51 to 54	52 to 56½
Ductility @ 25 C.	100 plus	12 to 28	14.5 to 20
Flash point, degrees C.	325	315-320	315-320
Volatilization @ 163 C.	0.1 %	0.1 %	0.1%

(continued)

Property	Asphalt	5% Rubber in Asphalt	7½% Rubber in Asphalt
Solubility in C S 2	99.5%	94.9%	92.4%
Insolubility in CCl 4	0.3%	5.2%	7.6%
Oliensis spot test	negative	negative	negative

Observations are being made from time to time of the experimental paving in Akron by comparing the appearances between the ordinary asphalt surfacing and the rubberized asphalt surfacing; but of course, several years will elapse before sufficient observations will make the effect of weathering and wear apparent.

The rubber powder used in the Akron experiments was prepared in the Goodyear Pilot Plant. At present, the rubber is available for experimetal purposes at a cost of a dollar a pound Should the rubber be produced on a volume basis, however, Goodyear estimates the cost of about fifty cents a pound. It is estimated that the rubber for a square yard of such a surface, one inch thick, should not exceed six or seven cents. European experience has been that the savings realized through the reduction in maintenance more than justified the additional costs of rubber powder addition.

It appears from the foregoing, tht the adding of synthetic of rubber powder is far the best method of producing rubberized asphalt pavements. It produces all the advantages realized from a rubber-asphalt surface, while being the least expensive and the simplest to introduce.

The city of Akron has recently started another experimental section. Also Virginia and Texas is experimenting with rubberized asphalt pavements. However this type of pavement will not be commonplace for several years.

Following will be found certain technical data as to composition of mixes, changes in properties of the asphalt cement after adding rubber and other data.

TECHNICAL DATA

W. Exchange St. Re-Surfacing
Broadway - Maple St.

Job started Sept. 7th, 1948

Sept. 16th.	Began surface course 5% rubber - North half from West Line Broadway to Canal Bridge.
Sept. 17th.	Surface course 7½ rubber - North half from Canal Bridge to about 50' West of West Line of Locust Street.
Sept. 23rd.	Began surface course 5% rubber - South half from Maple St. to West Property Line of Bishop St.
Sept. 24th.	Surface course 7½ rubber - South Half from West Property Line of Bishop to Front #188 W. Exchange St.
Leaving about	400 Ft. Lineal Feet between the above two sections on which a seal coat (coffee grounds) was applied on regular surface-material extending from 50 feet West of Locust St. 200 ft. to about the East line of Pine Alley - full width.

Job completed Sept. 30th., 1948.

Quantities of Materials Used

Binder Course ---	2862	Tons
Surface Course --	1768	Tons
	4630	Tons

The leveling course or binder course was composed of limestone and sand for the mineral aggregate and "Sohio" asphalt for the bitumen combined to meet the following specification:

Passing Sieve	Retained on Sieve	Minimum %	Maximum %
1 inch	3/4 inch	0	5
3/4 inch	1/2 inch	5	20
1/2 inch	3/8 inch	7	30
3/8 inch	No. 4	10	35
No. 4	No. 6	0	10
No. 6	No. 50	20	45
No. 50	No. 200	3	15
No. 200		0	5
Bitumen		6	10
Total Retained on No. 6		40	55

Actual box weight in lbs. of the surface course materials at the asphalt plant are shown by the following data taken from some of the daily plant reports:

	Regular Mix	5% Rub.	Regular Mix	5% Rub.	Regular Mix	7½% Rub.	Reg. Mix	7½% Rub.
A.C.	130	136	136	140	136	150	136	150
Sand	850	850	850	850	850	850	850	850
Stone	1020	1014	1014	1010	1014	1000	1014	1000
Total	2000	2000	2000	2000	2000	2000	2000	2000

The following analyses are typical of those shown on some of the daily plant reports:

	Regular Mix	5% Rubber	Regular Mix	7½% Rubber
Bitumen	6.6%	5.8%	6.2%	6.6%
Passing 1/2" sieve	6.1%	2.9%	5.9%	2.3%
Passing 3/8" sieve	33.0%	34.3%	32.6%	32.2%
Passing No. 4 sieve	8.4%	10.8%	10.4%	10.5%
Passing No. 6 sieve	36.2%	40.1%	41.1%	49.4%
Passing No. 50 sieve	6.5%	4.4%	6.5%	3.8%
Passing No. 200 sieve	3.2%	1.7%	3.5%	1.8%
Retained on No. 6	47.5%	48.0%	48.9%	45.0%

As the writer has tried to show in this thesis the three processes or introducing rubber in asphalt for pavements which seem practical and economical are: (1) the mixing of asphalt with a solution of light oil and granulated rubber; (2) the latex emulsion process, and (3) a process being developed in the United States, and being far more simple, although possibly more expensive in foreign countries, the addition of synthetic rubber powder to the asphalt mix.

The main advantage to a rubberized asphalt pavement is the reduced susceptability to temperature changes, while no sweating occurs in warm weather. However, it is necessary to correct the reduced adhesion. One solution to this problem is the addition of a thin coat of pure asphalt to the aggregate surface. Of course, it would be more advantageous if the diminished adhesion could be restored by some direct treatment of the binder, permitting us to use this improved type of binder in place of an ordinary asphalt binder in all types of applications, but essentially in the resurfacing of worn road surfaces by seal-coats. In this type of resurfacing it is advantageous to employ a binder remaining firm in warm weather and not sweating. However more experimental research must be done with regard to the problem of adhesion.

Another important advantage is a greater elasticity of the pavement, and consequently less tire wear and quieter driving. It would seem advisable to coat new concrete roads with a thin rubber asphalt layer, making the highway water tight, lending smoother riding, and giving extra long service, if a new top is laid about every ten years. The properties of the binder are further improved by air-blowing.

Many authorities are of the opinion that the Broome method is the most suitable in the U.S.A. The Standard Oil Development Company states that

> The considerable amount of admixed light oil solvent which is used for dissolving crude rubber can perhaps be distilled off by reduced pressure from the finished binder...eliminating the loss of this solvent and hastening setting.

It is also the opinion of this company that the larger oil producing concerns should incorporate the rubber.

However, using synthetic rubber powder as developed by Good-year, this method seems totally unnecessary.

But what ever the best method of incorporating the rubber, the additive facilitates the manipulative process of the mix by increasing penetration, ductility, and plasticity.

In the writer's opinion, the synthetic rubber powder is far the superior additive in existence. Because of its economy and the ease by which it is introduced, synthetic rubber powder will eventually lay the foundation of commonplace rubberized asphalt pavements in America.

EXPLANATION OF PHOTOGRAPHS

Photograph #43-A:

Synthetic rubber powder, being poured into hot asphalt by employees of the Thorpe Construction Company, preparatory to resurfacing a section of an Akron street with the new "hot-mix" material.

Formula called for 1,200 pounds of rubber powder to 3,000 gallons of asphalt, plus crushed rock; resulting in 180 tons of mixture for the resurfacing job.*

Photograph #43-D:

Thorpe Construction Company workmen spread new "hot-mix" material containing synthetic rubber at a busy intersection of Exchange Street, in Akron, O. Furnished by Goodyear Tire & Rubber Company, the synthetic rubber powder is said to increase waterproofing qualities of the "hot-mix" used in street resurfacing. It also gives longer wear, is more resistant to cold and has greater skid-proof tendencies.*

Photograph #43-E:

Workmen for the Thorpe Construction Company spread and roll new "hot-mix" material containing synthetic rubber, in resurfacing an Akron Street. The occasion is believed to be the first in which rubber was used in a major resurfacing job in this country. The synthetic rubber powder employed in the "hot-mix" was furnished by Goodyear Tire & Rubber Company.*

*All titles and photographs courtesy Goodycar Tire and Rubber Company.


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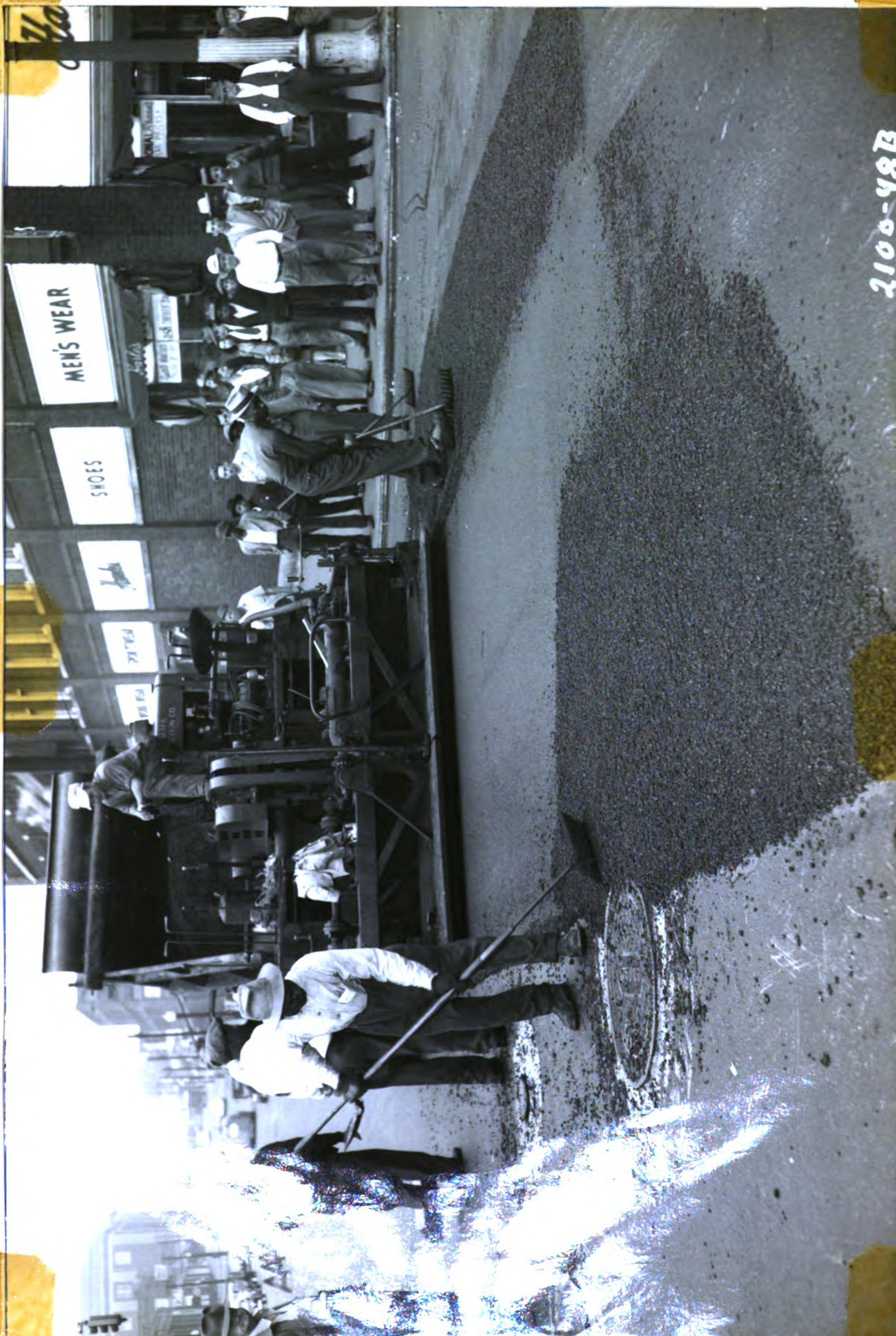
MEN'S WEAR
SHOES
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MEN'S WEAR


ASSOCIATION

BIBLIOGRAPHY

I. Bulletins and Letters

The City of Akron, "Street Resurfacing with Rubberized Asphaltic Concrete."

Endres, H. A., "Use of Synthetic Rubber Powder in Asphalt Pavements."

Goodyear Tire and Rubber Company, "Powdered Rubber in Asphalt Mixtures."

Standard Oil and Development Company, Letter to Michigan State Highway Department.

Thurm, R, "Rubber Asphalt Mixtures for Asphalt Surfaces," July 23, 1927.

II. Articles

Bie, G. J. Van Der, and Wijnhamer, "Application of Rubber Powder to Asphalt Road," Roads and Streets, 84: 36-40, November, 1941.

Broome, D. C., "Elastic Bitumens," Society of Chemical Industry Journal, 64:149-151, 1945.

______, "Rubber and Asphalt Mixes for Road Construction," India Rubber World, 97:37-40, December, 1937

Davey, W. S., "Physical Properties of Rubber - Bitumen Mixtures," Society of Chemical Industry Jounal, 55:43, March 6, 1943.

Eckert, G. W., "Bitumen - Rubber Mixtures for Road Construction," India Rubber World, 100:37-9, July 1939.

Fermin, B. W. H., "New Rubber Road; Abstract," India Rubber World, 97:75, January, 1938.

Fol and Plazier, "Influence of the Addition of Rubber on the Properties of Bitumen," Wegen, April 1, 1947.

Plaizer, J. A., "Asphalt - Rubber Road Mixtures," Rubber Age, 44:343, March, 1939.

Ponal, Maurice, "A Description and Critical Comparison of Methods of Incorporating Rubber in Bitumen for Surfacing Roads," Revue Generale du Caoutchone, 22:182-8, September, 1945.

"Powdered Rubber Admixture," Roads and Streets, 91:82, December, 1948.

"Road Surfacing Experiments in France," Roads and Roads Construction, p. 16, January, 1949.

Rooijen, J. M. van, "System Asphaltic Bitumen - Rubber Powder," Industrial and Engineering Chemistry, 33:820-4, June, 1941.

"Rubber Bitumen Roads," India Rubber World, 94:61, July, 1936.

"Rubber in Asphalt," Science News Letter, 54:73, July 31, 1948.

"Rubberized Roads," Science Digest, 24:96, Spring, 1948.

"Rubberized Streets, Akron, Ohio Experiments with Synthetic Rubber Mixture," American City, 63:105, November, 1948.

"Rubber Paving," India Rubber World, 95:71, January, 1937.

"Rubber Street Paving," India Rubber World, 96:67, April, 1937.

III. Patents

Austrian patent #150,006 (June 25, 1937).

British patent #10,327 (by Cassell, 1844).

British patent #231,503 (by Van Haagen).

British patent #464,522 (April 20, 1937).

ROOM USE ONLY