PAPER NO.596

# RUTTING OF BITUMINOUS CONCRETE PAVEMENTS

BY

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## ABSTACT

The AASHTO recommended Bituminous Concrete Pavements construction in Pakistan is not an old phenomenon. Lahore-Sahiwal Highway was perhaps the first major Highways Project in Punjab where bituminous concrete was used as structural element. This was designed, supervised and constructed by local consultants (NESPAK) and contractors(Saad Ullah and Brothers) respectively. Prior to this Hydrabad Bypass was the only other major highway where bituminous concrete had been used as a pavement structure. In the last decade or so number of projects have been intiated in which multi layer bituminous concrete pavement has been adopted as pavement element. The most important of them are N-5, N-25, Lahore Islamabad Motorway and Asian Development Bank aided Provincial Roads Improvement Programme (PRIP). Some of these roads on completion have opened to traffice and many others are expected to become operational by the end of 1998. Similarly many hundred kilometers of highways are in design stage where bituminous concrete will be used as major structural element. Thus with the increase in length of bituminous concrete will be used as major structural element. Thus with the increase in length of bituminous concrete paved roads each year, which of course is very expensive proposition, it is all the more important that highway engineers should be aware of the problems and recent advancement in field of the bituminous concrete pavement design and construction. The motivation behind this article is to share experience with colleague engineers in the best interest of the motherland.

## HISTORY

In the early seventies of the twentieth century, as a consequence of famous oil boom asphalt concrete pavement construction was adopted by almost all the Middle Eastern countries. Kingdom of Saudi Arabia and other oil rich Gulf States in particular took lead. In Saudi Arabia alone thousands of Kilometers of expressways (motorways) had been completed by the year 1995. Some of the important ones are Jeddah-Macca Al Makarma, Macca-Al Makarma Madina Al Munawar Dhahran Abu Hydriah and Jeddah-Riyadh Dammam Expressways. There was no indigenous asphalt concrete pavement design and construction technology in these states, therefore, engineers from US Corps of Engineers and other US Federal Road Agencies were called, to fill in the prevalent vacum of technical know how. In order to pave the way for transfer of technology, as early as January 1972, the General Specification for Road and Bridge Construction, Ministry of Communications were published in Kingdom of Saudi Arabia. Almost for all the bituminous concrete pavements, till 1985 were designed on the basis of the guide lines provided by these specifications. In one way or other similar type of asphalt concrete specifications have been adopted or are being recommended for future projects in Pakistan.

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Marshall Mix Design Method for asphalt concrete has universally been accepted. However, Marhsall Method of Mix Design was primarily meant for temperate climates where the road surface temp was not to exceed 60°C with standard axle loading. While adopting Marshall Method of Mix Design this very fact has been ignored by the highway engineers in the middle East and Pakistan. In the mid 1980's and onwards, the phenomenon of permanent depression under wheels (rutting) was observed on many Highways/Expressways in Saudi Arabia as well as in other neighboring Gulf States. Similar problems have been encountered on asphalt concrete paved roads in hot and dry regions of Punjab. The failure of Lahore-Sahiwal Highway in eighties was an example of this phenomenon. Luckily the author was stationed in Saudi Arabia at that point of time and had first hand knowledge of the steps and research conducted in Riyadh (Ministry of communications Asphalt testing laboratory). Extensive at site monitoring was conducted to overcome the problem of rutting which even shook US experts. After research and great efforts altogether new parameters for the Marshall Mix Design have been fixed and subsequently used successfuly. The experience with specifications used for Provincial Highways Projects and failure of N-5 project, particularly rutting of Gujranwala Kharian stretch, the author is convinced that mix design parameters are not being understood properly in this part of the world. In this technical paper an attempt has been made not only to highlight the causes of rutting but also preventive techniques have been discussed in length. There is dire need to understand the phenomenon of rutting and this could only be achieved by research work. We must come up with indigenous methods to overcome the problem of rutting.

## CAUSES OF RUTTING OF BITUMINOUS CONCRETE PAVEMENTS

In order to understand the mechanism of rutting which is one of the most common forms of asphalt pavement distortion besides shoving, corrugations, depression and upheavels, it is of paramount importance to understand various parameters which effect the behavior of asphalt concrete from manufacture in the asphalt plant to performance on the road. All those factors which increase or decrease rutting have been discussed hereunder with the same objective. Despite the fact that a lot of research work in this field has been done, yet different variations occuring over the full range of temperature have not been related directly with rutting of bituminous Concrete pavements.

### Job Mix Formula

The general specification for Road and Bridge Construction, Ministry of Communication, Kingdom of Saudi Arabia published in 1972 provided for the following guide line for the Mix Design.

"The Marshall Test procedure will be used to determine the percentage of liquid asphalt that is to be incorporated into the mixture. Open bituminous mixes deteriorate rapidly in Saudia due to the drying and oxidizing effect of the Sun, therefore, the mix will e densely graded and relatively on the high side of the fines. For the same reasons, a low asphalt content in the mix is detrimental. The Job-Mix will therefore provide for as high an asphalt content as possible for a mix designed by the Marshall Test procedure. The mix formula will also take into consideration the absorpotion of the asphalt into the aggregates. Thus, for

calculation for voids the adjusted build specific gravity of the Marshal Specimens, adjustment for the portion of the asphalt test by absorpotion shall be used".

In order to achieve the above mentioned goals the following combined mineral aggregates gradings were specified.

| AASHTO SIEVE SIZE | Bituminous Base Course (B.B.C.) Class A | Class B | Bituminous Wearing Course (BWC) Class A | Class B |
|---|---|---|---|---|
| 1-1/2" | 100 | 100 | - | - |
| 1" | 100 | 80-100 | - | - |
| 3/4" | 80-100 | 70-90 | 100 | 100 |
| 1/2" | - | - | 80-95 | 80-100 |
| 3/8" | 60-80 | 55-75 | - | - |
| No. 4 | 45-65 | 44-62 | 48-62 | 50-70 |
| No.10 | 30-50 | 33-48 | 32-45 | 32-47 |
| No. 40 | 15-32 | 16-27 | 16-26 | 16-26 |
| No. 80 | - | - | 8-18 | 10-18 |
| No. 200 | 3-10 | 3-10 | 4-8 | 4-10 |

It was further specified that job-mix formula shall combine the mineral aggregates and asphalt in such proportion sa to produce a mixture confirming to the following composition limits by weight.

| Properties | B.B.C |
|---|---|
| Total Mineral Aggregates % | 96-93 |
| Asphalt Binder % | 4-7 |

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When tested according to the Marshall Method, the bituminous mixture shall confirm to the following requirements.

| Properties | B.B.C | BWC |
|---|---|---|
| Stability (kg) | 500 | 700 |
| Flow (mm) | 2.4-5.0 | 24-4.0 |
| Voids in total mix (%) | 3.0-7.0 | 3.0-5.0 |
| Voids filled with asphalt (%) | 60-70 | 70-80 |

In short the job mixes were recommended to be designed to fulfill the following two basic requirements.

1. Mixes should be densely graded and low in voids.

2. Mixes should be rich in asphalt content.

These two factors combined with heavy axle load and high temperature have been reckoned as the major factors which have caused rutting of bituminous concrete pavements in the kingdom of Saudia Arabia.

Quality of Aggregate Base Course and Placement

Unlike water bound macadam used in Pakistan, aggregate base course Class-A or B with the following combined gradings were specified.

| Sieve Size | Class A | Class B |
|---|---|---|
| 2 1/2" | 100 | - |
| 2" | 90-100 | - |
| 1 1/2" | 80-90 | 100 |
| 1" | 42-77 | 60-100 |
| 3/4" | 35-70 | 55-85 |
| 1/2" | 25-60 | 35-60 |
| No. 4 | 15-40 | - |
| No. 10 | 10-26 | - |
| No. 40 | 5-15 | 15-30 |
| No. 200 | 2-9 | 8-15 |

Compared to water bound macadam, aggregate base course does not provide good interlocking and adequate bearing value, though the specified CBR Values could easily be achieved. The Class B grading in particular in some way contributes to the rutting. The aggregate base course placement techniques were also not spelled out properly in specifications. It has been found that, if aggregate base course or sub-base is allowed to be mixed at site, it disturbs the layers beneath and ultimately contributes towards rutting of the asphalt pavement.

High Temperature

During the day time the pavement temperature as high as 75°C was recorded on Riyadh Dammam Expressway and with sand drifting across the road, the temperature effect could still be higher than the one reported here. Similar conditions are prevalent in Southern Punjab and desert regions of Baluchistan and Sind. Marshall mix design which is based on the upper high pavement temperature limit of 60°C is apt to rut in such regions unless due care is exercised.

Heavy Axle and Traffic Loads

The Marshall method of mix design provides for preparation of Marhsall specimens by applying 75 blows on its both faces. The specified compaction to be achieved in the field generally varies in the range of 96% to 98% of Marshall bulk specify gravity (Gmb). Once

pavement is compacted to specified compaction its relative density should not increase under any loading conditions. However, within first year of the opening of the expressway to the traffic relative densities as high as 103% were observed. It meant undesirable zero void condition which may have caused rutting. It has further suggested that compacting effort of the heavy axle load is much more than the effort specified to prepare Marshall specimen in laboratory. Once zero void condition is reached asphalt is apt to rut.

Multi Layer Asphalt Construction

It is matter of common observation that the phenomenon of rutting is much more pronounced where asphalt concrete has been placed in more than one layers. Bituminous concrete is supposed to behave as flexible pavement during its service life. In case of multi layer asphaltic concrete construction due to undesirable variation in stability and flow values i.e., low value in the upper layer than the one next below, changes the behaviour of the pavement from flexible to semi rigid and due to this undesirable transition ultimately it yields (plastic failure) under heavy loads, causing rutting of the pavements.

Early Opening of Road to Traffic

Early opening of the road to traffic, particularly when road studs have been installed, compels the traffic to move in certain fixed pattern. The wheels of the slow but heavily loaded trucks always fall on the same track. This repitition of load coupled with semi plastic behaviour of asphalt concrete explained above causes rutting in the slow lanes in particular.

Compaction

Sometimes due to non availability of proper equipment in number and weight results in poor compaction of bituminous concrete pavements during the construction of the pavements which ultimately leads to rutting.

Quality Aggregates

Excessive thin and elongated (more than 15%) uncrushed aggregate particle provide poor inter locking properties leading to rutting of asphalt concrete pavements.

## FIELD OBSERVATIONS AND RESEARCH WORK

The construction of multi million dollar Riyadh-Dammam Expressway commenced someitimes in early 1982. This gigantic project spread in 480 kms length was divided into eight sections. The work of seven sections was alloted to International Contractors where as only one section (section #8 near Dammam) was entrusted to a local contracting concern. The scheduled construction period was two years. However, after two and half years of vigrous efforts section #1 & 2 were completed (author was Resident Engineer at Section #2). In reality it was put to incremental use i.e. as it was being contructed traffic was operating on it. This resulted better re-adjustment of aggregates and bitumen within asphalt concrete mass. Ultimately when road studs were installed it had already acquired balance in its internal

behaviour. The construction work on section #6 was behind the schedule. There was great pressure to open the expressway. The time gap between completion of wearing course and installation of road studs was almost nil. Once road studs were at place they guided the traffic movement giving no time for internal adjusts in asphalt concrete mass. As the consequence of this within two months after the opening this section to traffic the signs of rutting were observed. Naturally it stunned all concerned. Field investigation teams were formed. The author was given the opportunity to represent Rashid Engineering Riyadh (Supervision Constultants) in one of such committees headed by Dr. Nova, UN expert of Philippines origin. Extensive field observation and investigations were carried out and the following short term conclusions and recommendations for the remaining works were ordered.

1. The phenomenon of rutting started in slow lane only and was particularly severe in irght carriageway, where heavily loaded traffic, from sea port of Dammam to Riyadh was operating.
2. Section No. 6 had been opened to traffic immediately after the installation of road studs.
3. The sample cores taken from the rutted area indicated that bituminous concrete pavement had attained relative compaction of upto 103% where as at the time of construction it was compacted to specified requirment of only 96% to 98% of the Marshall bulk specific gravity (Gmb).
4. In almost all the cases it was observed that upper layers had penetrated into the lower layers. This phenomenon in particular was true for wearing course which had penetrated into bituminous base course layer below.
5. Cracks either on the surface or within the core itself were not obseved.
6. No distress was observed at aggregate base couse or sub-grade level.
7. The approved mix design was too rich in asphalt content.
8. The dolomite (rock) available in the nearby vicinity had been used as basic aggregate material. This rock had tendency to break into thin and elongated particles, providing poor interlocking properties.

Keeping in view the above observations, mix design in vogue was revised on the following lines.

1. Coarses grading (upper limit) of the mix was recommended.
2. The bitumen content in the mix was reduced.
3. At this point of time emphasis on shape of aggregate was also given e.g. the contractor of section 8 (where the author had been tranferred after completion of section 2) was compelled to use aggregates from the Abu Hydriah guarry. The aggregates obtained from this source were cubical in shape.

Keeping in view the above stated guide lines, the wearing course and other remaining asphalt works at section 8 were completed. The author visited this section of road again in 1994, by grace of God no distress even after eight (8) years was observed.

Extensive research work was carried between 1987 to 1990. After a hard research work and a thought process, ultimately the following guide lines for the future Mix designs

have now been adopted. The bituminous concrete mix conforming to these design parameters have passed the test of time.

## PREVENTIVE MEASURES

### Optimum Asphalt Content

The optimum asphalt content has been recommended to be based on a percent asphalt content having atleast 4.0% air voids for both Base Course and wearing Course mixtures. The asphalt content thus determined is used to check for compliance for stability, Flow and voids filled etc. as per the specifications. This will effectively reduce the asphalt content in the mixture and increase its resistence to rutting. As long as minimum stability, maximum flow voids filled and other specification criteria requirements are met, the mixture will provide the maximum performance for the specific combination and gradation of aggregates and asphalt.

### Mix Design Criteria

Procedure for calculating air voids using the adjusted bulk specific gravity (General specifications section-(3.O5 Material 3. Job Mix) was one of the four methods recommended by the Asphalt Institute in 1963. The current recommendation in the Asphalt No. 2 (M2-2) May 1984] is based on non-adjusted bulk specify gravity. These calculations Provides for more accurate stock of voids in the mix.

### Mix gradation.

The gradation of the Job-Mix materials should be towards the coarser end of the Specifications as outlined below.

| Sieve Size | Class-A Base Course | Class-A Wearing Course |
|---|---|---|
| 3/2" | 100 | 100 |
| 1" | 100 | 100 |
| ¾" | 85 | 100 |
| ½" | - | 85 |
| 3/8" | 65 | - |
| No.4 | 50 | 53 |
| No.10 | 35 | 36 |
| N0.40 | 20 | 20 |
| No.80 | - | 12 |
| No.200 | 4.5 | 5.0 |

Only Base Course Class- A and wearing course Class- A have been recommended.

**Marshall Mixing Temperature.**

The mixing temperature of 160±5 °C at which the heated asphalt produces a Kinematic viscosity of 170+20 centi stokes has now been recommended.

**Marshall compaction Temperature.**

The compaction temperature of 145±5 °C at which heated asphalt produces a Kinemitic viscosity of 280 + 3 centi stoke has now been recommended.

## Mix Placement and Compaction

**Tack coat.**

Tack Coat shall not be required between two lifts of bituminous courses when the Previous lift is less then two days old. When Tack Coat is required the application shall be very light (0.10 to 0.15 liters per square meter) Excess asphalt will seriously affect the life of the pavement.

**Placement.**

The mixes manufactural by the above criteria will be coarser and have less workability than one it used to. This will also reduce rutting. Therefore, special emphasis shall be placed on the condition of the paver ( particularly the screed), temperature control and the overall paving operation.

**Compaction.**

Because such mix is designed to resist rutting under traffic, it will also be more resistive to initial compaction. Optimum attention must be given to rollers and rolling the mat. The mixture has to be compacted to optimum field density to develop the total potential of the pavement.

**Some other requirements**

a) The ratio of Filler to Binder should range from 1-1.5.
b) The percentage of Natural sand in fine Aggregate should not exceed 15%.
c) The material to be crushed shall be screened on 1-1/2 Sieve and only retained material is to be crushed:-

x) The above stated provisions made in the job mix formula shall produce a mixture confirming to the following requirements.

| PROPERTIES | B.B.C. | B.W.C |
|---|---|---|
| Voids in Mineral Aggregates | 15% | 13% |
| % Air voids | 5-8 | 4-7 |
| Marshall Stability | 1000 Min | 1000 Min |
| Marshal flow(mm) | 2.0-3.5 | 2.0-3.5 |
| HVEEM STABILITY(Min) | 40 | 40 |
| Softening point (Filler/Acp) °C | - | 85-95 |
| Filler/Asphalt Ratio | - | 1.0-1.5 |

xi) It is clear that contrary to previous practice where mix was recommended to be dense and rich, the emphasis now is that a mix should not reach zero void condition under any loading condition during its service life. This could only be achieved when the mix is coarser and rich in voids. ( Min 4%). Recently refusal method of mix design (Percentage Refusal Density Method) has been recommended. In this method mix in the laboratory is subjected to unlimited blows till it refuses to get compacted further ensuring that the air contents do not fall below 2%.

xii) It has been experimented beyond doubt that with rise in temperature above 60 °C the mix laid on the road does not remain as stiff as it must be to resist deformation under heavy wheel loads and therefore yields to permanent deformation (rutting). Perhaps it is due to revival of lubricating effect of bitumen at higher temperatures. This problem is tackled by increasing the softening point of the mix and is achieved by adjusting filler- Asphalt ratio. In case of surface course desirable range in between 85-95 °C. The addition of fines enhances the viscosity and increases the chances of the mix to resist rutting even at high temperatures. Now days lower grade asphalt such as 40/50 penetration and sometimes modified polymer asphalt is being recommended to increase the softening point and thus creating effective shield against the tendency of rutting.

xiii) With the decrease in asphalt content and more voids in the mix the chances of progressive loosening or separation of aggregates particles in a pavement surface (ravelling) may increase, however, a film thickness of 58 micron (tested with ball and ring test) around the particles ensures reasonable safety against ravelling. This is why

harder asphalt cements are being recommended for heavy duty pavements and for hot weather construction. High penetration grades like 85/100 will not produce a thick film of coating around the particles. This will turn the mix unstable, undurable and low in voids.

## Crushed Aggregate Base Course

It has been mentioned while discussing causes of rutting in bituminous concrete Pavements that aggregate base course material compared to water bound macadam does not provide adequate support. Attempts have been made to improve the quality as well as grading (making it coarser) of the crushed aggregate base course (ABC). The crushed ABC with the following properties is widely being recommended:-

The aggregate shall be either crushed stone, or crushed gravel. The fine aggregate Shall be screening obtained from crushed stone, gravel or slag. The crushed gravel shall consist of hard durable stones, rocks, and boulders crushed to specified sizes and shall be free from excess flat, elongated, soft or disintegrated pieces, dirt, or other objectionable matter. The method used in production of crushed gavel shall be such that the finished product shall be as uniform as practicable. The crushing of the gravel shall result in a product which shall have at least 90% by weight of particles with at least two fractured faces and 100% by weight of particles with at least one fractured face. All stones, rocks, and boulders of inferior quality occurring in the pit shall be wasted. The crushed aggregate shall have a percent of wear not more that 40% at 500 revolution and shall not show evidence of disintegration nor show a total loss greater than 12% when subjected to sodium sulphate accelerated Soundness test.

All material passing No.4 mesh sieve produced in crushing operation, either from stone, gravel, or slag shall be incorporated in the base material unless there is an excessive amount which, if included, would not meet the gradation requirements. The Crushed aggregate shall meet the following grading requirement.

| Sieve Size | Passing % |
|---|---|
| 2" | 100 |
| 3/2" | - |
| 1" | 55-85 |
| ¾" | 50-80 |
| #4 | 30-60 |
| #40 | 10-25 |
| #200 | 3-10 |

The gradation in the table represents the limits which shall determine suitability of aggregates for use from the source of supply. The final gradation selected from within the limits designated in the table shall be all graded from coarse to fine and shall not vary from the low limit on one Sieve to the high limit on the adjacent Sieve or vice Versa.

By Imposing Axle Load Restrictions.

The rutting of bituminous concrete pavement almost certainly begins from the slow lanes (truck lanes) of the expressway. It has been established that axle load is closely related to rutting. When Riyadh Dammam Expressway was opened to traffic in mid eighties the legislations restricting axle load to 13 tons had the approval of monarch but it was not being practiced. Due to oil boom the economy was growing rapidly and every other vehicle operating on the road network was grossly violating the provisions of the law. When the multi million dollar expressways started deteriorating fast due to over loading, the leading, the legislation was put to practice and weigh bridges at inter changes were established to impose the axle load restrictions. By imposing this law investment worth billions of U$$ has been saved.

Like saudi Arabia law restricting axle load in Pakistan too exists but there is no will to impose the law. The failure of Lahore-Sahiwal Highway, Sangiane Taxla dual Highways near Islamabad and in the recent past N-5 (particularly Gujranwala Kharian Secrion) are few of the examples where rutting besides other factors has been caused due to excessive axle load. The elected representatives should exert for the implementation of the law. In the beginning it may adversely affect the transport industry in Pakistan but at the end of the day every body will be benefited. The axle load restrictions on expressway/motorway could be imposed mor easily as it has controlled access and exist. The Lahore- Islamabad Motorway must be protected from the menace of unrestricted axle load.

**Restriction On Multi layer Asphalt Conerete Construction.**

Bearing in mind the very hot climatic conditions in Pakistan the asphalt layers should be restricted to maximum of 12 cms in two layers (8cms B.B.C and 4 cms B.W.C). It has been observed that more the number of asphalt layers the more are chances of rutting of asphalt concrete pavement. The designed structural number of pavement should be achieved by way of increasing the thickness of good quality crushed aggregate base course.

Recently the author only after great efforts, could convince the designer, who happened to be a foreign consultant, to omit leveling course provided in certain reaches of Jhang Chiniot Road. The project is part of Provincial Road Improvement

Programme Currently being implemented with the assistance of Asian Development Bank.

**Restriction On Installation of Road Studs Or Cat eyes**

In case of Riyadh Dammam Expressway it was observed that those sections of the Expressway (e.g. Section 6) which were opened to traffic immediately after installation of road Studs saw the phenomenon of rutting much earlier than the sections where roads studs were installed atleast four to five months after the opening of road to traffic. Once the road studs are installed the slow moving traffic is restricted to the same lane and the wheels repeatedly track the same path. This repetition of wheel load ultimately causes plastic failure of the pavement (rutting). It would be much more safe if the white road studs on lane lines are not installed at all, however, yellow road studs on the edge lines could be installed on motorways and Highways in Pakistan. This is all the more necessary in case of Lahore- Islamabad Motorway where lane width has been reduced to 3.50 m from standard AASHTO lane width of 3.65m.

**By Introducing Polymer ( Primarily Polyolefin) Modified Asphalt**

This technology has been introduced in Saudi Arabia in the recent past by under the trade name of NOVOPHALT. It has been declared as an outstanding invention in the field of asphalt pavements. novophalt has been developed by Richard Feisinger Group of Austria and perfected over the past 15 years. Numerous highways and airfields have been constructed using the novophalt binder. The novophalt technology has been used in various climatic zones in Europe and overseas, and all applications demonstrated the superior performance of novophalt. The temperature range within which this asphalt concrete mixture supports a design load without unddue distress is extended by using a proven modifier. This decrease in temperature susceptibility of the mixture is attained by lowering the temperature limit at which the binder film in the mix would crack and by increasing the upper temperature limit at which the binder would soften, thereby preventing rutting and cracks in the pavement. The novophalt binder enhances the properties of asphalt mixtures in the following way.

The first step of novophalt binder is to select a base bitumen' the properties of which ( penetration, viscosity) will ensure that cracking does not occour at the lowest temperature expected at the plant site, based on the test procedures developed by Hills or Arard. The temperature will be further extended by the selection of special additives within the novophalt binder system. The novophalt modification increases the softening point (Ring and Ball ) which will significantly reduce rutting at the highest temperature expected at the project location.

The modification itself is carried out by adding selected hydrocarbon based

Polymers to the asphalt. It is produced in accordance with a patented novophalt process using a mobile blenders set up at the site of the asphalt hot mix plant.

The polymerized hydrocarbon (Primarily polyolefines) have a significantly greater molecular weight then those of which the base bitumen is composed. The polymer additive contains a long chain on backbone, and small side branches which control the degree of crystallinity, on which it promotes adhesion to the aggregates. The improved edition explains way the Novophalt binder increases mixture tensile properties before and after exposure to moisture.

## CONCLUSIONS

The most important improvements imparted by Novophalt on asphalt hot mix can be summarized as follows.

a) Much improved resistance to rutting.
b) Reduced crack formation at low temperature.
c) In creased load distribution capacity of the pavement.
d) Reduced fatigue due to traffic loads.
e) Increased adhesion and reduced stripping due to exposure to moisture.
f) Low aging, especially as a result of exposure to UV radiation.
g) Better resistance to damage from lube oil and fuel.

## REFERENCE

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