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STRIPPING PHENOMENON IN BITUMINOUS MIXES: AN OVERVIEW

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Abstract

Striping is one of the main causes due to which distresses in the bituminous layers occur. Moisture presence results in weakening or eventual loss of adhesive bond of bitumen from aggregate. Nowadays, the roads are lacking in respect of proper drainage facilities, which is one of the main reasons for road damage due to stripping. For prevention of damage due to stripping, adequate drainage must be provided. Stripping can cause complete failure of the pavement. Inadequacy in quality of roads affects the quality of life and further hinders the development of country.

A brief overview of the stripping phenomenon of bituminous mixtures and research in the field over the past years has been presented in this paper. The contents of the paper include mechanism of moisture damage occurrence and contributing factors, as well as an introduction to the variety of methods to experimentally evaluate the stripping value. Suggestions for future investigations and reducing stripping value have also been presented.

Keywords: Stripping, Moisture, Bituminous roads

I. INTRODUCTION

One of the fundamental properties for good performances of bituminous pavement is proper adhesion between aggregate and bitumen. Moisture presence in bituminous pavements is a primary cause which results in weakening or eventual loss of adhesive bond of bitumen and aggregate. This phenomenon is known as stripping.

The existence of water in bituminous pavement is often one of the major factors affecting the durability of Hot Mix Asphalt (HMA). For prevention of damage, adequate drainage must be provided. Nowadays, the roads are lacking in respect of proper drainage facilities, which is one of the main reasons for road damage due to stripping. Stripping can cause rutting ravelling, bleeding, cracking and formation of potholes and culminate with complete failure of the pavement.

In India, method of determination of stripping value of road aggregates (IS: 6241-1971) is the standard describing the stripping test for the coarse aggregates. The test is designed only to capture the amount of stripping in the presence of water. What is being put forth in this paper is a summary of extended researches having been conducted on the reasons and causes of stripping by different researchers during the past several years.

Also, it is intended to take a look at studies which have been done with the aim of evaluation and estimation of stripping in bituminous mixes considering the achievements and shortcomings of each. Finally, the new areas of research based on the improved understanding of stripping are introduced.

II. MECHANISM OF STRIPPING

Stripping is generally defined as "the breaking of the adhesive bond between the aggregate surface and the bitumen". Several mechanisms have been suggested to explain the occurrence of stripping. It appears that these mechanisms may act individually or together to cause adhesion failure in bituminous mixtures.

The water induced damage in HMA layers may be associated with two mechanisms: loss of adhesion and/loss of cohesion. In the first mechanism, the water gets between the bitumen and aggregate and strips the bitumen film away, leaving aggregate without bitumen film coverage, as illustrated in Figure 1 and Figure 2. This is because the aggregates have a greater kinship for water than bitumen binder. The second mechanism includes the interaction of water with the bitumen that reduces the cohesion within the bitumen. [1].

There may be five different mechanisms by which stripping of bitumen from an aggregate surface may occur. These five mechanisms [3, 4], include detachment, displacement, spontaneous emulsification, pore pressure, and hydraulic scouring.

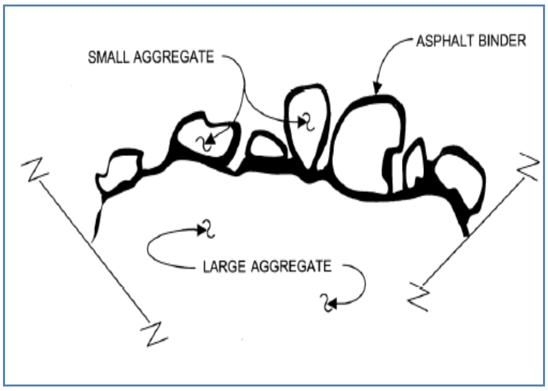

Fig. 1 HMA at the Time of Mixing [2]

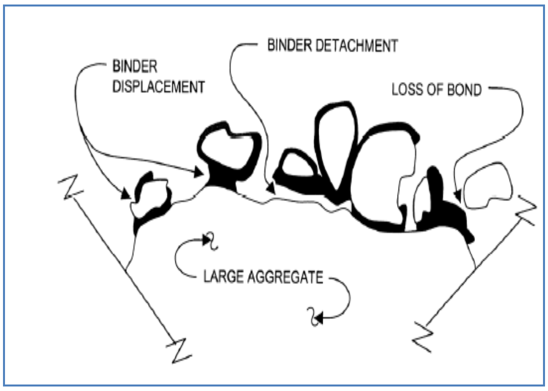

Fig. 2 Displacement and Detachment of Asphalt Binder in the Presence of Moisture [2]

Brief description of each suggested mechanism of stripping follows:

Detachment

Detachment is separation of bitumen film from an aggregate surface by a thin layer of water, with no obvious break in the bituminous film. Where stripping by detachment has occurred, the bitumen film can be peeled cleanly from the aggregate, indicating a complete loss of adhesion.

Displacement

Stripping by displacement results from the penetration of water to the aggregate surface through a break in the bitumen film. The break can be caused by incomplete coating of the aggregate initially or by film rupture. Because the bitumen film at these locations is generally thinner and under tension, rupture of the bitumen film is probably at the sharp edges and corners of angular aggregate pieces as a result of traffic loading.

Spontaneous Emulsification

In spontaneous emulsification, water and bitumen combine to form an inverted emulsion, where bitumen represents the continuous phase and water represent the discontinuous phase. The formation of such an emulsion leads to stripping and is further aggravated by the presence of emulsifiers such as mineral clays and some bitumen additive.

Pore Pressure

Pore pressure has been suggested as a mechanism of stripping in high void mixes where water may circulate freely through interconnected voids. Upon densification of the mix from traffic loading, water may trap in impermeable voids that previously permitted water circulation. Further traffic may induce high excess pore pressure in the trapped water causing stripping of the bitumen film from the aggregate.

Hydraulic Scouring

Hydraulic scouring is a mechanism of stripping that is applicable only to surface courses. Stripping due to hydraulic scouring results from the action of vehicle tires on a saturated pavement surface. This causes water to be pressed down into the pavement in front of the tire and immediately sucked away from the pavement behind the tire. This compression-tension cycle is believed to contribute to the stripping of the bitumen film from the aggregate.

III. CAUSES OF STRIPPING

Some of the aggregates are inherently susceptible to stripping. However, there are also other external factors and in-place properties that lead to the deterioration of the HMA. Some of the other factors for the moisture induced stripping of the HMA are as follows:

Inadequate Pavement Drainage

Inadequate surfaces or subsurface produce water or moisture vapour, which is the necessary catalyst to induce stripping. There have been case histories where stripping was not a general phenomenon occurring on the entire project site but only in areas that were over-saturated with water due to inadequate drainage [5].

Water can enter the HMA pavement in many ways. It can enter as surface runoff from cracks and other openings. It can also enter from the sides and the bottom as seepage from ditches or from a high water table. Water often moves upward by the capillary action from the bottom of the pavement. Many sub-bases and sub-grades in the existing highways lack the desired permeability, and are therefore, saturated with capillary moisture. The air voids in the HMA can become saturated with water, even from the vapour condensation from water in the sub-grade and the sub-base. A temperature rise after this saturation, and traffic stresses can lead to significant void pressure when the voids are saturated [5].

Properties of Water

Adhesion is strongly affected by pH of contact water which changes with temperature [6]. The pH causes a shift in angle of contact and significantly affects the wetting properties of bitumen. Weak acids affect some aggregate minerals like alkali feldspars. Interfacial tension is highest at intermediary pH values (up to 9) and drops with an increase of the pH to 14 [7]. The effect of water at the interface us aggregate specific.

Physical Properties of Aggregates

Physical properties of aggregates are important to study as they participate in the process of stripping. Aggregates surface texture, aggregate porosity and pore structures are also known to affect stripping.

It was reported that decreasing the aggregate size and increase in mastic asphalt would increase the stripping potential of hot mixes asphalt with dense gradation [8]. Also, they found that increasing the mastic asphalt would decrease the stripping potential of stone matrix asphalt (SMA) [9].

Inadequate Compaction

Most agencies specify air content in the HMA mat of about 8% during construction, which is further compacted by traffic to about 4-5%. Studies indicate that when the air content is about 4-5%, the pores are not interconnected, and thus almost impervious to water [5]. However, if good compaction control is not exercised, the pavement would have higher air content, leading to the ingress of water, causing moisture damage to the pavement. Also, if the pavement remains pervious to water for a long period of time, moisture damage can also be caused due to the hydrostatic pore pressure caused by traffic.

Excessive Dust Coating on the Aggregate

The presence of dust and clay coating on the aggregate can inhibit the intimate contact between the binder film and the aggregate, thereby forming channels for penetrating water. The binder coats the dust coating and is not in contact with the aggregate surface.

Some very clayey material may cause stripping by emulsifying the binder in the presence of water.

Action of the Traffic

After any rain shower, the water in the pavement is pressed into the underlying layer by truck tires. This causes tremendous hydrostatic stresses, leading to the breaking of the bond between the binder and the aggregate. This is especially severe in the case of open graded friction courses due to the high air content. Traffic stresses can also directly rupture thin bitumen films, especially around sharp aggregate corners. These ruptures act as avenues for moisture into the interface. The effect of traffic is supported by the usual occurrence of stripping first in the outer traffic lanes compared to the inner lanes [10].

Inadequate Drying of Aggregates

When the aggregate is coated with binder, a dry aggregate surface will better adhere to the binder than a wet surface. As the hot binder is introduced to the wet aggregate surface, the moisture on the surface of the aggregate vaporizes and does not allow the binder to coat the aggregate well.

Weak Aggregates

If weak and friable aggregates are used in the mix, degradation takes place during rolling and later under heavy traffic loads. Degradation and delamination exposes new uncoated aggregate surfaces that can absorb moisture and initiate stripping problems.

IV. FACTORS AFFECTING STRIPPING

Factors responsible for inducing premature stripping include [11]:

- Water in, or on, the Dried Aggregate - High water absorption and/or adsorption makes drying more difficult, and fine aggregates dry preferentially which may leave some moisture in the coarse aggregate, particularly under the partial vacuum conditions of the dryer/drum.
- Aggregate Type – 'Siliceous' aggregates more prone to stripping than 'carbonate' aggregates.
- Aggregate Surface Texture – 'Smooth' surface texture less resistant to bitumen stripping than rough surface texture.
- Dust-Coated Aggregate - bitumen does not adhere properly and dust creates film defects.
- Stockpile Age - Some newly crushed aggregates exhibit poor resistance to bitumen cement stripping.
- Spontaneous Emulsification – Anti-stripping agents can become stripping agents under certain conditions.
- Bitumen Cement Properties - The chemical and physical properties of each bitumen cement are unique, and can dramatically influence the stripping behavior of a bitumen mix.
- Hot-Mix Design, Production and Placement - High in-place air voids, for instance, can promote water movement.
- Free Water Availability to bitumen Pavement Structure.

V. METHODS TO PREVENT STRIPPING

The best way to prevent stripping will be to test the mixture in the laboratory and to use an aggregate/binder combination that does not strip. However, this will not always be possible due to many reasons such as, lack of suitable aggregates, increased costs in the transportation of certain aggregates, political constraints, etc. Even in spite of having the mix not be susceptible to moisture in the laboratory, there is not much certainty that the mix will behave the same in the field. Different types of aggregate pre-treatments have also shown to improve the moisture susceptibility of the mix. Some of the pre-treatments include pre-heating the aggregate to evaporate the moisture, weathering, washing to remove surface dirt, crushing, etc. It has also been shown that aggregates coated with asphalt or other recycled materials are better at resisting the moisture damage in the HMA than are virgin materials [12].

Yildirim et al [13] showed that polymer modified binders showed greater resistance to fatigue, thermal cracking, rutting, stripping, and temperature susceptibility than neat binders and exhibited increased viscosity and elastic recovery.

P.K. Jain and J B Gupta [14] reported in their study that indirect tensile strength under specific conditions of moisture soaking and immersion correlate well with stripping area of aggregates to an extent of 90-100%. They suggested the addition of dehydrogenated tallow di methyl amine in bitumen to prevent stripping in presence of detrimental salt ion.

U. Bagampadde et al [15] investigated the impact of bitumen and aggregate composition on stripping in bituminous mixtures using four bitumen and four aggregates. It was found that mixtures made with lower penetration grade bitumen exhibit higher tensile strength in dry and wet conditions.

Martin Hugener et al [16] investigated that a water conditioning temperature of 19° C causes no bitumen debonding from the aggregate for the bitumen investigated. With increasing conditioning temperature, the coating degree declines and the difference between the two binders grows. A mixing temperature of T_R -15° C is suggested where T_R is reference temperature.

Y. Liu et al [17] determined that Bituminous mixtures containing limestone aggregates have better moisture resistance than granite aggregates based on results from loose bitumen coated moisture sensitivity tests. For unmodified mixtures, stiffer binder (40/60) provides better moisture resistance compared with softer binder (160/220), based on loose bitumen coated moisture sensitivity tests.

VI. TESTS FOR EVALUATING STRIPPING VALUE

Different experiments are performed for identifying stripping value of bitumen from an aggregate in different countries. Some commonly adopted tests for determining stripping value are:

- American Society for Testing and Materials (ASTM)

In order to indicate relative water susceptibility of bitumen-coated aggregate and identify possible problems related to it, ASTM comprise of two tests for determining effect of water on bituminous coated aggregate [18].

Static Immersion Test (ASTM D 1664)

Boiling Water Test (ASTM D 3625)

- California Test (302)

California test 302 is modified version of test procedure AASHTO T 182 (Coating and Stripping of Bitumen-Aggregate Mixtures) [19].

- Film Stripping Test

(AASHTO American Association of State Highway and Transportation Officials)

- Bureau of Indian Standard (IS)

Bureau of Indian Standard of testing comprise of only one test for determining de-bonding or stripping of bitumen from an aggregate. Method of Test for Determination of Stripping Value of Road Aggregate (IS: 6241-1971) [20].

Difference in Test and Field Conditions of Stripping

Most of the methods used across the world uses almost same methodology and varies the quantity of material or mixing heating temperature of aggregate and bitumen. Also, for determining stripping value visual observation is done which can vary for each individual which effects accuracy of stripping value. Many a times it is experienced that stripping of aggregates takes place on the road even when lab tests indicate no stripping. Though it is not easy to exactly simulate the field conditions in the lab, it should be ensured that field conditions of contact time and pH value of water with aggregates and field temperature are maintained as closely as possible in the lab during the test.

Conditions which are not involved in laboratory tests but show their presence in the field and affect stripping are presented in Table-1.

Table 1 Difference between Lab and Field Conditions [21]

S.No	Factors affecting stripping value	Lab condition	Field condition	
		Status	Status	Effect
1.	Tyre friction	Absent	Present	Hydraulic scouring occurs in Surface course of pavement due to friction produced by tires of vehicle.
2.	Temperature variation	Absent	Present	Sample tested under constant temperature condition collapses in field where change in temperature occurs.
3.	Traffic load	Absent	Present	Hydraulic scouring occurs due to moving traffic load on saturated pavement which is addressed as pumping action in some researches.
4.	Time of contact of water with mix	Sample is kept for 24 hours under water according to IS: 6241-1971.	Contact time of water will depend on drainage and other factors.	Stripping of aggregate is directly proportional to its time of contact with water. Hence, surplus contact of water will enhance stripping value.
5.	pH of water	Distilled water is used in experiment which is neutral(pH=7)	There is a huge variation in pH value of water in field.	Water with high pH value is a major involving factor in the process of stripping. Hence, to minimize chances of striping maintain pH value of water as low as possible.
6.	Quality control	Static	Dynamic	Variation in the quality of mixture enhances possibility of stripping of aggregate.
7.	Bitumen-aggregate mixing/coating	For small sample, we get perfect mixing/coating.	On large scale, probability of error increase.	Inadequate quality of aggregate-bitumen mixture and non-uniformly coated aggregates are more prone toward stripping.
8.	Precipitation	Absent	Present	Snow and rainfall are main factors which participate in stripping if proper drainage facility is missing.
9.	Freeze-thaw cycles	Absent	May be present depending upon region	During freeze/thaw cycles water present in voids change to ice and occupies 9% more volume than water, which results in internal de-bonding.
10.	Stress	Absent	Present	Formation of tensile stress reaching as high as 20 psi has direct impact on stripping which is generated due to evaporation of water present in bitumen mixture void [4].

VII. CONCLUSION AND SCOPE FOR FURTHER RESEARCH

Despite a long history of research on the interfacial phenomenon of stripping, it is still obscure and no clear theory exists to explain it. A lot of research is still needed to explore it intrinsically. On the basis of literature review, the following conclusions and gap areas for further research are identified:

1. The evaluation methods consider mainly moisture sensitivity as the main factor due to which stripping occurs.
2. In laboratory distilled water is used in experimentation which is neutral with pH 7, but there is a large variation in pH value of water in the field.
3. In order to improve capability to predict long-term performance, and reproducibility and correlation between laboratory and field test data other conditions like wetting-drying cycles, acidic and alkaline conditions and altered temperature cycles need to be researched in detail which have been found missing in previous studies.
4. The effect of traffic load and tyre friction has not been taken up comprehensively in earlier studies.
5. No mechanism has been developed yet to determine stripping value, observations are done visually.
6. Several remedial measures have been tried to abate stripping in mixes. It is important to control the root causes of stripping before trying out anti-stripping agents.

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