

ADHESION OF ASPHALT TO AGGREGATES IN THE PRESENCE OF WATER

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SYNOPSIS

The general relations between coverage, wetting and adhesion are discussed and illustrated. Properties of viscosity, surface tension, surface texture, porosity, polarity and molecular orientation are described with reference to their effect upon the adhesion of asphalt to mineral surfaces. The characteristics of hydrophilic (water loving) and hydrophobic (water hating) aggregates are considered and general methods of increasing the preference of mineral aggregates for asphalt over water are explained.

Practical application of information at present available is indicated to the engineer and a number of rules of procedure are given for his guidance in the treatment of aggregates with asphalt. Methods of preventing asphalt film stripping are discussed and a simple test is described for evaluating the resistance of aggregates to asphalt film stripping in the presence of water. This test is also of value in determining the efficacy of chemical treatments of aggregates or asphalt to increase their adhesion to each other.

Basic principles are listed as follows:

- 1 Coverage of the aggregate with asphalt may often be obtained without wetting.
- 2 Thorough wetting of the aggregate with asphalt is essential to good adhesion.
- 3 While low viscosity in an asphalt is an aid to wetting an aggregate, high viscosity is an important deterrent to film stripping.
- 4 Mechanical manipulation is a powerful aid to thorough wetting.
- 5 Strongly hydrophilic (water loving) aggregates which are thoroughly wetted with asphalt may lose their adhesion to asphalt films in the presence of water.
- 6 Time is often an important element in developing maximum adhesion.
- 7 If strongly hydrophilic aggregates must be used under unfavorable conditions, recourse should be had to special treatment of the asphalt or aggregate.

To the physical chemist belongs the credit for having analyzed the factors which control the adhesion of asphalt to aggregates in the presence of water and of suggesting certain corrective procedures when satisfactory adhesion is not otherwise possible. However, in presenting the results of his investigations he introduces a multitude of expressions with which the highway engineer has never before had to concern himself. The terms hydrophilic and hydrophobic have jumped to the fore, surface tension, interfacial tension, multiple phase systems and free surface energy are used in such a carelessly familiar manner that the ordinary engineer may well become bewildered in attempting to follow these physiochemical discussions. However,

they sound intriguing and perhaps induce him to ask a few questions in an attempt to clarify the picture in his own mind. The physical chemist may then raise his brow (if that is possible) and come back with a simple explanation in which ions, valence, dipoles and molecular orientation play the leading rôles. At this point the entire subject becomes as clear as mud to the ordinary engineer who is apt to surrender with the conviction that either the chemist or himself is mentally unbalanced and with just enough doubt in his mind not to press the issue.

Now the ordinary engineer is at least a practical man and is capable of using information that he understands. It is not necessary that he become a chemist

to grasp the essentials of this subject any more than that the automobile driver become an automotive engineer in order to operate a motor car. It is true that the factors influencing the adhesion of asphalt to aggregates in the presence of water are varied and complex and it is also true that their correct interrelationship has not yet been completely evaluated even by the physical chemist. During recent years, however, certain facts have been learned regarding this matter which can be put to practical use by the highway engineer. It is the object of this paper to present these facts as briefly as possible without reference to their chronological development and without recourse to highly technical or detailed explanations.

Stripping of asphalt from mineral aggregate surfaces in the presence of water is no new phenomenon in the field of highway engineering. It has been observed at times ever since asphalt paving came into existence. Development of modern practice both in the use of lean open or semi-open type mixtures, and in surface treatments in which the asphalt films are usually quite thin, has served to accentuate this problem and the ever increasing use of asphalt in all highway programs has brought it to the personal attention of a great many highway engineers. Until quite recently the engineer faced with unsatisfactory results due to film stripping, was apt to place the entire blame on poor quality asphalt, but tests made on the asphalt seldom supported such a conclusion.

In many instances where the presence of water produced film stripping under service conditions, laboratory tests on the same mineral aggregate coated with the same asphalt used in the unsatisfactory work, were found to develop rapid and pronounced film stripping under the action of water. Other mineral aggregates coated with the same asphalt, however, often proved to be highly resistant

to film stripping. This fact has been demonstrated so many times that it is now generally recognized that the characteristics of the aggregate have a great deal to do with the adhesion of asphalt to their surfaces in the presence of water. It has usually been found that an aggregate which strips badly when mixed with a given asphalt will also strip badly when mixed with any other asphalt, although occasional exceptions have been noted. On the other hand an aggregate which is highly resistant to film stripping when coated with a given asphalt will usually prove highly resistant when coated with any other asphalt.

Adhesion of one material to another is a surface phenomenon and is dependent upon their intimacy of contact and the mutual affinity of the surfaces of the two materials. Asphalt has practically no affinity for water and if a water film exists between it and an aggregate surface, adhesion of the asphalt to that surface is prevented. Most aggregates on the other hand have an affinity for both asphalt and water. If the affinity of an aggregate for water is much greater than for asphalt then under certain conditions water may displace an asphalt film with which it is coated. By considering the factors which affect (1) intimacy of contact and (2) mutual affinity of aggregate and asphalt surfaces, it is possible to explain the adhesion or lack of adhesion of asphalt to aggregates in the presence of water.

Before the best possible adhesion between two substances is obtained it is necessary that their surfaces be brought into the most intimate contact possible. Intimate contact between two solids or between a solid and a semisolid is difficult to obtain unless one can be temporarily liquefied at the time contact is made. Thus while a lump of asphalt cement placed upon a mineral aggregate surface may adhere to some extent, adhesion is not nearly so perfect as when the

asphalt is first melted and then spread over the surface. It is for this reason that asphalts are applied in liquid form to aggregate surfaces. The ability of a liquid to make intimate contact with the surface of a solid is known as its wetting power, and the ability of a solid to make intimate contact with a liquid is known as its wettability. The wetting power of different liquids for a given solid may vary greatly and the same is true regarding the wettability of different solids for a given liquid.

with a solid surface. Other things being equal, the lower the surface tension the greater becomes the wetting power. Figures 1 and 2 illustrate the characteristics of viscosity and surface tension. In most cases the surface tension of asphaltic products decreases as their viscosity decreases. Water has a higher surface tension than most liquid asphaltic materials but its very much lower viscosity makes it in general a better wetting agent.

The wettability of an aggregate surface

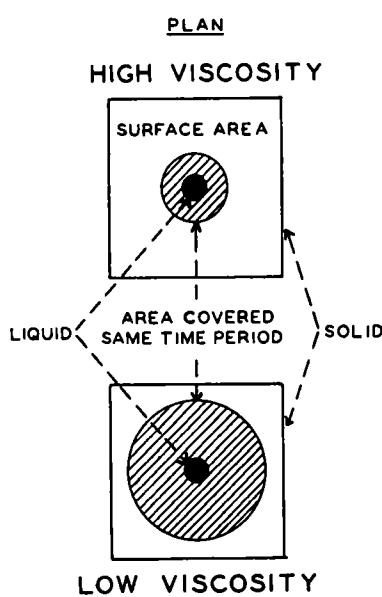


Figure 1. Viscosity

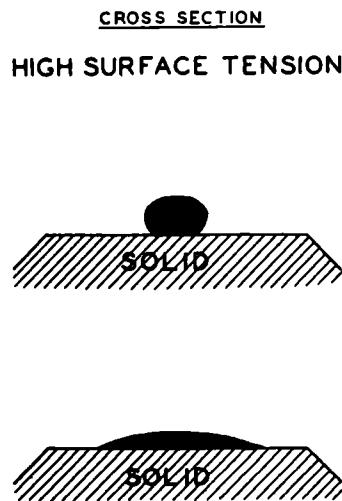


Figure 2. Surface Tension

The wetting power of a liquid is largely controlled by its viscosity. Other things being equal, the lower its viscosity or the greater its tendency to flow, the greater becomes its wetting power. Thus the wetting power of very liquid asphalt is greater than that of more viscous asphalt. Another important factor influencing wetting power is the surface tension of the liquid or the force tending to hold a drop of it in a spherical form, which force works against its tendency to spread or flatten out when brought in contact

is also controlled by a number of factors. Solids possess surface tension as well as liquids. In general, the higher the surface tension of the solid the greater is its wettability. When the surface tension of a solid exceeds that of a liquid it is more easily wetted than when the reverse is true. Surface texture is also a factor bearing upon wettability of the solid, a smooth surface being more readily wetted than a grainy one.

It is believed that enough has been said to illustrate the point that the rela-

tive wetting power of water and asphalt for various aggregate surfaces depends upon the balance created by a number of characteristics of the contacting materials. As water is usually the better wetting agent, when an attempt is made to coat a water wetted aggregate with asphalt, true adhesion of the asphalt to the aggregate surface is prevented unless the asphalt is able to displace the water film. Its lower surface tension is a factor which may make it possible to coat the water wetted aggregate surface under favorable conditions without actually adhering to it. As between aggregate and asphalt this property may be termed coverage. It should be borne in mind

aggregate surfaces is not, however, secured unless the asphalt ultimately replaces the water films.

Cut-back asphalt of low viscosity may be mixed with slightly damp aggregate so as to thoroughly coat it but if mixing is continued until the asphalt becomes highly viscous, it will often be found that coverage is almost entirely destroyed and the asphalt coalesces into clots or gobs owing to the fact that the water films have prevented true adhesion. This will not happen when the aggregate is thoroughly dry.

When aggregates are in an extremely fine state of subdivision as in the case of most soils, it is difficult to cover the individual particles with a liquid asphaltic product unless they are first surrounded

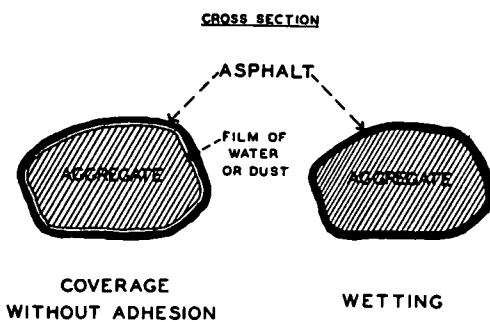


Figure 3

that while coverage is essential to wetting, wetting is not necessarily assured by coverage and as wetting is essential to good adhesion, coverage may be obtained without adhesion. These distinctions are illustrated in Figure 3.

Both coverage and wetting may be greatly facilitated by certain mechanical operations such as brushing, in the art of painting, and mixing or dragging in the art of road building. In certain cases coverage may be more readily effected over an aggregate surface containing a thin film of water than over a bone dry aggregate. This fact has been repeatedly noted in the priming and surface treatment of fine grained road surfaces. Perfect adhesion of the asphalt to the ag-

gregate surfaces is not, however, secured unless the asphalt ultimately replaces the water films. The asphalt does not readily wet the fine dry particles and under a mixing operation, tends to distribute itself in rather large globules throughout the mass. When the particles are moist, coverage may often be readily secured by mixing, but if an excess of water is present it may be prevented although the asphalt will then be quite uniformly distributed throughout the mass in the form of extremely fine threads. These three forms of asphalt distribution throughout the soil mass are illustrated in Figure 4. It is evident that if the asphalt is expected to serve as a waterproofing agent, it will be most effective when it not only covers the individual particles as in illustration B, but also displaces the water film and adheres to the aggregate surface.

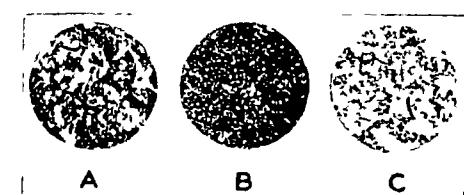


Figure 4

While it is necessary that an aggregate surface be thoroughly wetted by an asphalt before good adhesion between the two is secured, thorough wetting in itself does not necessarily insure good adhesion in the presence of water. Moreover, some of the factors that promote wetting are not advantageous from the standpoint of adhesion and a number of factors which tend to retard wetting may greatly increase adhesion once wetting has been secured.

The property of viscosity will serve as an example. While low viscosity greatly facilitates wetting, high viscosity facilitates adhesion once wetting has been secured. An asphalt film of low viscosity is much more readily removed from an aggregate surface, particularly if the surface is smooth, than is a film of high viscosity. Hot asphalt cements and cut-back asphalts as a rule adhere better than slow curing liquid asphalt products, the former because their viscosity increases as they cool to normal temperature and the latter because their viscosity increases with loss of volatile solvent.

Among aggregates those with a smooth surface may be most readily wetted but a rough texture surface is apt to produce greater adhesion under service conditions once the surface is wetted. Porous surfaces are also effective in promoting a strong adhesive bond between aggregate and asphalt. The asphalt film then extends below the outer surface and becomes mechanically interlocked in the rock structure as illustrated in Figure 5.

Probably the most important property affecting the adhesion of asphalt to aggregates in the presence of water is polarity. Mineral aggregate surfaces possess this property to a greatly variable extent and in general the same is true of liquids. Polarity as the name implies has to do with electronic or ionic charges occurring at points on the surface. Without attempting to develop the complex physio-

chemical aspects of this phase of the subject, the possible effects of polarity on adhesion of a liquid to a solid are roughly visualized in Figure 6. It is evident that where energy relations between liquid and solid are satisfied by the union of polarities of opposite signs, good adhesion will be secured, while the reverse is true where polarities of both are the same. The relative adhesion of two liquids for the same solid will depend largely upon their energy relationship to the surface.

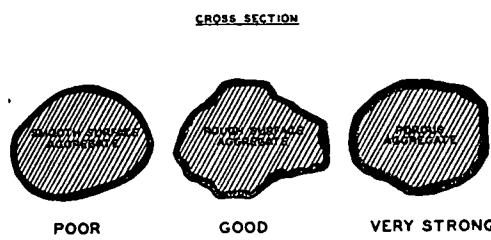


Figure 5. Effect of Aggregate Surface Texture on Adhesion.

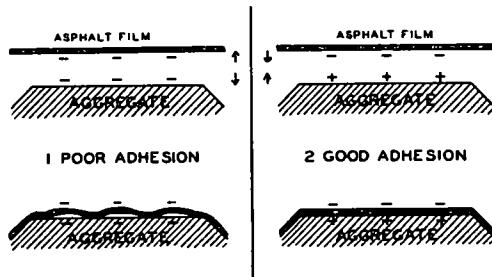


Figure 6. Effect of Polarity on Adhesion

of the solid. That liquid which satisfies the greater energy demand will adhere more tenaciously. If the energy relationship for two liquids differs greatly then, when afforded a suitable opportunity, the surface of the solid will preferably wet itself with and adhere to that liquid which satisfies the greater energy demand. This preference may be so strong under certain conditions as to cause replacement of one liquid film by another.

It is in this field that the physical chemist steps in to charm and bewilder the

unwary by his proclivity for theorizing and introducing mesmeric terms. In this atmosphere the terms hydrophilic and hydrophobic were born and are probably destined for permanent adoption in the highway engineering field. Hydrophilic means *water loving* and hydrophobic *water hating*. As applied to mineral aggregates, in connection with their relation to asphalt, hydrophilic means having a decidedly greater affinity for water than for asphalt. In fact the term is largely confined to aggregates which have so great an affinity for water that an asphalt film with which they are coated may be ultimately displaced by water. On the other hand, the term hydrophobic is applied to aggregates which will persistently retain an asphalt film in the presence of water. It is readily seen that the terms are more relative than absolute. Thus an aggregate may be slightly hydrophilic or strongly hydrophobic.

Frequently the element of time is an important factor in developing the maximum adhesion between an aggregate surface and an asphalt film. Asphalt consists of a combination of many hydrocarbon compounds. Therefore it is composed of molecules of widely different chemical composition. Most of these molecules appear to possess non-polar characteristics and develop no energy relation with a polar aggregate surface. A small proportion of the molecules, however, are known as dipoles, that is on one surface they carry a positive charge and on the opposite surface a negative charge. When a polar aggregate is wetted with an asphalt film these molecules will ultimately orientate themselves so as to satisfy the energy demands of the aggregate surface to the maximum of their capacity. Such behavior is illustrated in Figure 7.

Molecular orientation in viscous liquids and semisolids proceeds rather slowly. Therefore considerable time may elapse

before the maximum adhesion between an asphalt film and an aggregate surface is developed. It follows that an asphalt film when freshly formed may not develop sufficient adhesion to an aggregate to prevent it from stripping in the presence of water, whereas if protected from water action for a sufficient length of time it may become highly resistant to stripping.

Water molecules are all dipoles so that water possesses an advantage over asphalt in rapidly satisfying energy demands of polar aggregate surfaces. However, for some aggregates the asphalt dipoles may have a more powerful

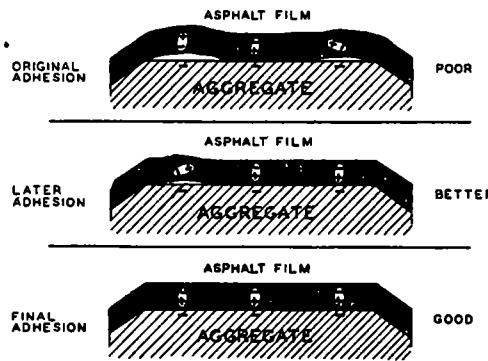


Figure 7. Molecular Orientation

energy demand than the water molecules and may thus be able to displace water.

There is one other factor bearing upon the adhesion of asphalt to aggregates in the presence of water, namely direct chemical reaction which may take place between certain chemical compounds on the aggregate surface and other compounds present in the asphalt. Thus organic acids in the asphalt may react with basic mineral substances to form other compounds which are insoluble in water but soluble or partially soluble in the asphalt. Powerful adhesion is then developed between the aggregate and the asphalt film.

Most aggregates are composed of a

variety of minerals, some of which may have been altered materially by weathering, at least in so far as their exposed surfaces are concerned. This is frequently true of a single individual fragment of the aggregate. Surface conditions at different spots on the same fragment may therefore vary appreciably with relation to a given liquid film. In other words adhesion of the film may be stronger over some areas than over other areas. When a hydrophilic fragment is coated with asphalt and then immersed in water, the asphalt film is first displaced where its adhesion is poorest. Just how film stripping may occur is shown in Figure 8, which is a series of three photomicrographs of the same aggregate fragment.



Figure 8

The first photograph shows the fragment uniformly covered with asphalt. In the second, water has displaced the asphalt film over certain areas and in the third, film displacement has progressed to the point where the asphalt is collecting in individual globules on the aggregate surface. Had this action been accompanied by mechanical agitation or abrasion, the asphalt might well have been completely removed from the aggregate fragment.

In the preceding discussion an attempt has been made to briefly describe and illustrate the properties of coverage, wetting, and adhesion of asphalt films to aggregates in the presence of water. The question now arises as to the practical use of such information. This phase of the subject may conveniently be considered from two different points

of view, that of the physical chemist and that of the highway engineer.

So far, the physical chemist has attacked the problem mainly from the standpoint of changing or controlling surface relations between aggregates and asphalt film by chemical means. From investigations so far conducted it appears that there are two methods of approach to this problem. The first has to do with the chemical treatment of hydrophilic aggregates so as to make their surfaces hydrophobic. Extremely thin coatings of certain substances which are insoluble in water but soluble in asphalt have proven effective in this respect, provided such treatment satisfied the energy demand of the aggregate surface better than water. As an example, furfural and certain resins have been found useful for this purpose, at least in so far as their use with some aggregates is concerned. Formation on the aggregate surfaces of water insoluble soaps by chemical reaction between natural or adsorbed mineral constituents and subsequent treatments with fatty acids, has also given some promising results.

The second method of approach involves treatment of the asphalt before it is applied to the aggregate surface. It has been found possible to energize asphalt very materially by introducing oil soluble or readily miscible compounds, the molecules of which are strong dipoles. It has been stated that asphalt itself contains some dipole molecules which tend to produce strong adhesion of the asphalt film if given time to properly orientate themselves. By materially increasing the quantity of dipoles in the asphalt, surprisingly rapid results are sometimes obtained. So far the most encouraging have been secured with metallic salts of certain organic acids, particularly the fatty acids.

The ordinary oil in water type of asphalt emulsion contains water soluble soap which consists of dipole molecules.

The ability of these emulsions to readily coat damp aggregates is well known. However, the freshly coated aggregate may readily be stripped of its film in the presence of excess water. To become resistant to stripping, the film must first actually dry out. The inverted asphalt emulsion or the water in oil type has often been found to deposit an asphalt film with a strong adhesive bond on an aggregate surface, not only when the aggregate is damp but when it is actually immersed in water. It would appear that this is not so much due to the inverted state of the emulsion as to the fact that the emulsifying constituents used in its production have not only been powerful dipoles but also water insoluble. At any rate asphalts combined or energized with such dipoles, without emulsification, may actually displace water films on a hydrophilic aggregate.

From what has been said of the efficacy of chemical treatments of aggregates and asphalts in developing and maintaining mutual adhesion in the presence of water, it might be assumed that the problem has already been solved. There is a nigger in the woodpile, however, that must either be eliminated or taken into account. This is the fact that a given treatment which appears to be entirely satisfactory in connection with the use of one aggregate may not be equally effective with some other aggregate. In other words, no general panacea has as yet been developed and proven by service results. This problem is still engaging the attention of the physical chemist. In view of the many variable factors to be taken into account in the broad field of mineral aggregates and also in conditions attending their use with asphalt, further investigation of the subject is much needed.

Now let us see what practical use of information so far developed can be made by the ordinary engineer. A brief recapitulation of the basic principles rela-

tive to adhesion of asphalt to aggregates may be helpful at this point. They may be enumerated as follows:

1 Coverage of the aggregate with asphalt may often be obtained without wetting.

2 Thorough wetting of the aggregate with asphalt is essential to good adhesion.

3 While low viscosity in an asphalt is an aid to wetting an aggregate, high viscosity is an important deterrent to film stripping.

4 Mechanical manipulation is a powerful aid to thorough wetting particularly when the asphalt product is highly viscous.

5 Strongly hydrophilic aggregates which are thoroughly wetted with asphalt may lose their adhesion to asphalt films in the presence of water under certain conditions.

6 Time is often an important element in developing the maximum adhesion of an asphalt film to an aggregate surface.

7 If strongly hydrophilic aggregates must be used with asphalt under conditions where water action will be severe there are a number of methods of treating the aggregate or the asphalt to develop sufficiently strong adhesion to prevent film stripping in the presence of water.

Certain general rules of procedure are obviously indicated. Some of them are well known but frequently violated and in case of a failure which may have been caused by such violation, the excuse most often advanced is that when the same fundamentally bad procedure was followed on some other project no failure occurred. Such a statement may be quite true but is not a justifiable excuse because we know that a great many factors influence the adhesion of asphalt to aggregates, and chance conditions may be so favorable in some individual case that failure may not occur in spite of violation of obviously sound procedure. If the

engineer is really anxious to secure good adhesion between asphalt and aggregate he should observe the following rules, some of which will undoubtedly seem trite

1 *See that the aggregate is as dry as practicable before application of the asphalt* If no moisture originally exists between the aggregate surface and the asphalt, film stripping may not occur even on a hydrophilic aggregate unless later exposure to water is very severe and continuous or the aggregate is extremely hydrophilic in character Hot mix types of pavements in general have proven highly resistant to deterioration by film stripping, use of thoroughly dry aggregates in the preparation of such mixtures being undoubtedly a strong contributing factor In the case of some soil mixtures a certain percentage of moisture may be necessary to secure good coverage by the asphalt This, however, may not be as serious as in a pavement or surface course

2 *See that the aggregate particles are as free as possible from dust coatings* Coatings of a clay-like character which tend to adhere strongly to surfaces of the coarser fragment should be particularly avoided and their use is specifically forbidden in specifications for hot mix types of construction Loose dust particles are not particularly objectionable in most of the mixed types of construction but frequently prevent proper wetting of aggregate fragments applied as a cover coat in surface treatments It is often difficult to obtain dust free cover material and when an objectionable amount is present it may be advantageous to premix the aggregate with a very small amount of kerosene before applying it to the road surface Such practice has recently been found to be beneficial in surface treatments in Connecticut Kerosene readily wets the surfaces of the dust particles and because it is soluble in asphalt, facilitates the wetting of the en-

tire aggregate by asphalt when it is later applied

3 *See that all aggregate surfaces are uniformly coated with as thick films of asphalt as are compatible with the type of construction adopted* Continuity of films makes it difficult for water to later find access to the aggregate surface and the same is true of thick films, properly applied Nothing can take the place of thorough mixing

4 *When using liquid asphaltic road materials, to coat cold aggregates under conditions where exposure to severe moisture conditions may be shortly expected, use a product of as high initial viscosity as practicable as well as one which will increase in viscosity after application* While an RC-1 grade of cut-back may be quite satisfactory for general surface treatments, RC-4 which has a much higher viscosity will be much more likely to adhere to an aggregate applied as a cover coat if the surface treatment is closely followed by a severe rain storm

5 *If a soft asphalt cement is used for surface treatment in cool weather, pre-heating the cover aggregate will be well worth while* Although the asphalt cement is applied hot to the road surface it chills quickly and will not readily wet a cold cover aggregate If, however, the cover aggregate is hot when applied it remelts the asphalt and keeps it in liquid form until the aggregate surfaces become thoroughly wetted

6 *Protect asphalt coated aggregates as thoroughly as possible from prolonged contact with water* Asphalt mixtures should be designed to be as impervious to water as possible High density and low voids are fundamentals of hot mix design and under ordinary conditions insure good adhesion in the mixture after compaction Such mixtures may be and have been entirely satisfactory in this respect, even when constantly immersed in water as has been very definitely proven by over five years' experience in the use of such

mixtures for underwater revetment on the Mississippi

If open type mixtures are to be used they should be thoroughly sealed at the surface and protected at the bottom by an asphalt primed base to prevent accumulation of water within the mix

Surface treatments cannot of course be protected from rainfall but the surface of a pavement is never continuously wet and just as time is an important element in securing the maximum possible adhesion between an asphalt film and an aggregate surface, it is also a factor in film stripping under the action of water. The most dangerous period for a surface treatment is the first few days of its life. Cold wet weather during this period may cause severe film stripping to occur under traffic when the same treatment applied under normally favorable conditions would have been entirely satisfactory. Rigid restriction of such work to suitable seasonal or weather conditions will prove to be a tremendous help in securing adequate adhesion of the asphalt to the aggregate. The engineer who applies surface treatments during the late fall, winter or early spring months under our ordinary climatic conditions is courting trouble unless he takes extraordinary precautions which are described under "8."

7 *Wherever practicable avoid the use of highly hydrophilic aggregates.* When a choice between aggregates is possible select the one that shows the greatest resistance to film stripping when coated with the type and grade of asphalt product that has been selected for use. No standard test has as yet been developed for this purpose, but the engineer may use a very simple method, later described, as a guide in selection when a choice between aggregates is possible.

8 *When a hydrophilic aggregate is the only one available for use or when under the stress of circumstances it is imperative to place surface treatments or to lay road mix-*

surface courses during unfavorable weather, recourse should be had to special treatment of the aggregate or asphalt, which treatment the engineer has in advance convinced himself by simple tests will enable asphalt to displace a water film on the aggregate.

While not yet in common use, chemically treated or energized asphalts are obtainable and in certain cases have produced remarkable results when used under extremely severe conditions. Before using such products the engineer should, however, convince himself that they will perform satisfactorily with the particular aggregate he proposes to use.

Pretreatment of aggregates has not as yet been developed to the point where commercial aggregate producers can guarantee to supply a hydrophobic product. There are, however, great possibilities in this field which in some respects appear more desirable than to attempt to develop an energized asphalt satisfactory for use with all aggregates. In fact it would seem quite possible that any aggregate producer could, with a little study based upon facts that the physical chemist has already developed, find some method of treating his own particular aggregate so that it would possess a strong affinity for asphalt in the presence of water. If he could then market such a product at a reasonable profit the problem would be solved without depending upon the possible development of a general panacea in the form of energized asphalt.

Some of the needed aggregate treatments might prove quite simple and inexpensive. For instance it has been observed that high temperature treatment of some hydrophilic aggregates may destroy or greatly modify their strong energy demand for water. In the laboratory, high resistance to asphalt film stripping has in some cases been developed by heating a strongly hydrophilic aggregate to a temperature

of 400°F., after which it has been allowed to cool before mixing with asphalt

Precoating a thoroughly dry aggregate with an extremely thin film of asphalt cement offers great possibilities to the aggregate producer. One or two per cent of asphalt applied as an asphalt cement to hot aggregate or as a cut-back mixed with cold aggregate and the mixture then allowed to season for a short time under cover may prove highly advantageous. When the asphalt films are kept very thin the coated aggregate particles will not adhere to each other but are water repellent. Unless the aggregate is very highly hydrophilic, such precoated aggregates are readily wetted with a thicker asphalt film even in the presence of water. They should often prove particularly well adapted for use in surface treatments.

Surface treatments with liquid asphaltic products and aggregate cover are more prone to rapid film stripping in the presence of water than most other types of construction, particularly if the treatment is closely followed by a heavy rain before the asphalt films have developed high viscosity. Rubber tires are hydrophobic in the presence of asphalt and if the aggregate is at all hydrophilic, they accumulate asphalt films as they pass over the surface and may strip not only the asphalt but also many small aggregate particles from the road surface. A surface that is well primed before the carpet treatment is applied will materially aid in holding the aggregate particles on the surface, and sometimes with acidic types of aggregates, a very light application of hydrated lime to the wet surface may assist in retaining the films on the aggregate surfaces. In the laboratory it has been found possible to coat certain wet aggregates with cut-back asphalt and obtain good adhesion when the wet aggregate was first mixed with less than one per cent of hydrated lime.

Such procedure is not by any means suggested as a cure-all but it may be found useful in certain instances.

The question will undoubtedly occur as to how he may determine in advance of use whether or not an aggregate is hydrophilic, and if so to what extent. In regard to this question it must be admitted that rocks cannot be definitely classified as hydrophilic or hydrophobic on the basis of their mineral composition and that so far no generally accepted method of test has been standardized. As a matter of fact, it is doubtful if any single procedure will be found entirely satisfactory for all purposes. The principal object of any test should be to determine suitability for use. Conditions attending use vary greatly in different types of asphalt construction. In a practically impervious mixture which will not be subjected to unusually severe water action, a hydrophilic aggregate may often be safely used while under more severe conditions, the same aggregate may be highly objectionable. It is quite probable therefore that a number of methods may be developed for use in the laboratory, each of which will have its special application. This problem remains for the chemist and materials engineer to solve. In the meantime, however, a very simple procedure may be used as a guide to selection in case there is a choice of aggregates and as a means to determine the efficacy of any special treatment given the aggregate or the asphalt to increase adhesion between the two in the presence of water.

A suggested rough procedure adapted for field use is appended.

SUGGESTED TEST FOR RESISTANCE TO FILM STRIPPING

The aggregate and asphalt product contemplated for use should first be well mixed in substantially the same proportions that they would be used in actual construction, care

being taken to see that all particles are thoroughly coated.

The aggregate should be of the same gradation as will be used in construction and should be like it in all respects. Freshly broken fragments should not be used for the test unless freshly broken material is to be used in construction practice, as the surfaces of freshly broken rock may possess quite different properties from those of even slightly weathered fragments.

If the construction calls for use of a hot mix then the test mixture should be prepared at the same temperature as that called for in practice and the same is true of cold mixtures.

After the mixture has been made it should be spread out in a loose thin layer and if hot, allowed to cool to normal temperature. Mixtures made with liquid asphaltic products should be allowed to air season for 24 hours before testing.

A suitable size sample of the cold mixture should be placed in a glass jar fitted with a tight screw cap and completely covered with distilled water. The jar and contents should then be kept undisturbed for a period of 24 hours, after which the mixture should be examined for evidence of film stripping. If film stripping at this time is pronounced the

aggregate should be classed as highly hydrophilic, particularly if it is of uniform mineral composition. In the case of aggregates in which individual fragments vary widely among themselves in mineral composition, as for instance gravel, it may be found that only a certain fraction of the total shows evidence of film stripping and that the remainder is hydrophobic.

The jar and contents should now be hand shaken quite vigorously for three periods of 5 minutes each, and the mixture examined at the end of each period. If no film stripping or very slight stripping is noted at the end of the third period of shaking, little or no trouble may be anticipated under ordinary conditions of use.

Parallel tests made on two mixtures using different aggregates will indicate which, if either, is to be preferred. The efficacy of any proposed special treatment of aggregate or asphalt may be similarly evaluated.

It should, of course, be realized that the above method can at best be considered only as a rough guide and it is suggested merely as a stop gap until more refined methods have been widely accepted and standardized for general use.

DISCUSSION ON ADHESION OF ASPHALT

DR. L W SHUGER, *Baltimore Paint and Color Works*: Have there been any tests made to indicate whether or not the electrode of the asphalt would be plus or minus or is that just a theory which most physical chemists would assume?

MR. HUBBARD I believe that a good deal is theory. However, from such information as is available relative to the composition of asphalts there is good reason to believe that dipole molecules may be present.